

# Space Shuttle/Payload Interface Analysis (Study 2.4) Final Report

Volume IV

Business Risk and Value of Operations in Space  
(BRAVO)

Part 2 - User's Manual

Prepared by  
ADVANCED VEHICLE SYSTEMS DIRECTORATE  
Systems Planning Division

15 February 1974

Prepared for OFFICE OF MANNED SPACE FLIGHT  
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION  
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THE AEROSPACE CORPORATION

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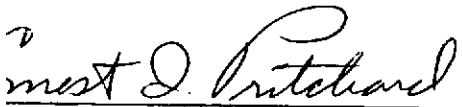
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SPACE SHUTTLE/PAYLOAD INTERFACE ANALYSIS (Study 2.4)

FINAL REPORT

Volume IV: Business Risk and Value of Operations in Space (BRAVO)  
Part 2: User's Manual

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## FOREWORD

The Space Shuttle/Payload Interface Analysis (Study 2.4) Final Report is comprised of five volumes, which are titled as follows:

- |                    |            |   |  |           |
|--------------------|------------|---|--|-----------|
| 15771              | Volume I   | - | Executive Summary  | N74-12493 |
| 15772              | Volume II  | - | Space Shuttle Traffic Analysis                           | N74-14530 |
| 15773 <sup>x</sup> | Volume III | - | New Expendable Vehicle with Reusable Solid Rocket Motors |           |
|                    | Volume IV  | - | Business Risk and Value of Operations In Space (BRAVO)   |           |
|                    |            |   | Part 1 - Summary   |           |
|                    |            |   | Part 2 - User's Manual                                   | ✓         |
|                    |            |   | Part 3 - Workbook  | ✓         |
|                    |            |   | Part 4 - Computer Programs and Data Look-up              |           |
| 15774 <sup>x</sup> | Volume V   | - | Payload Community Analysis                               |           |

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## 1. INTRODUCTION

The purpose of the BRAVO User's Manual is to describe the BRAVO methodology in terms of step-by-step procedures. The BRAVO methodology then becomes a tool which a team of analysts can utilize to perform cost-effectiveness analyses on potential future space applications with a relatively general set of input information (see Section 3) and a relatively small expenditure of resources.

An overview of the BRAVO procedure is given by describing the complete procedure in a general form in Section 2.

## 2. GENERAL PROCEDURE

For each user problem the BRAVO team accomplishes an analysis by carrying out the following steps:

- (1) Definition of the problem (BRAVO input)
- (2) Space system analysis
  - (a) Select system approach(es) and goals
  - (b) Satellite mission equipment selection
  - (c) Select specific satellite interface concepts
  - (d) Spacecraft synthesis
  - (e) Space system cost estimating
  - (f) Satellite system optimization analysis
- (3) Terrestrial system analysis
  - (a) Define
  - (b) Estimate costs/revenues
- (4) Cost-effectiveness analysis

The above activities are carried out in discrete steps, with sufficient interrelationships to minimize iteration (see Figure 2-1). The terrestrial system analysis is worked in parallel with the space system analysis. The following subsections describe the above steps:

### A. STEP 1 - DEFINITION OF THE PROBLEM (BRAVO INPUT)

The general input information provided by the system user source is first reviewed and certified to assess its content and insure its consistency. This information is then redefined (if required) as technical analysis inputs, along with additional technical inputs specified by the analyst to complete the data package, and the resultant technical information re-certified with the user source. The satellite system goals, functions,

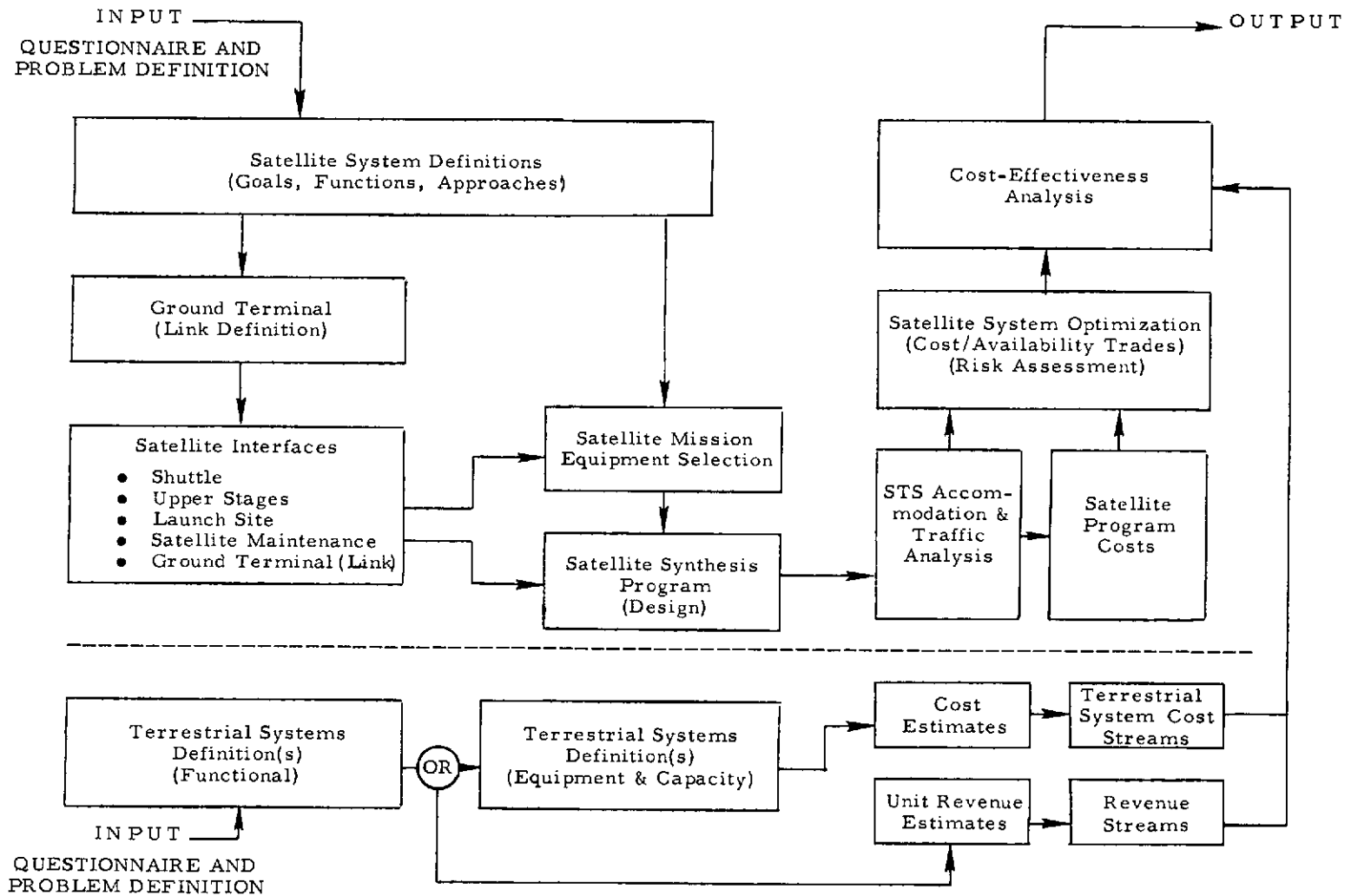


Figure 2-1. BRAVO Information Flow

and approaches are then generated, using the guidance for selection of space system optimized approaches and playing the goals and functions against the space systems scenario to insure appropriate compatibility.

## B. STEP 2 - SPACE SYSTEM ANALYSIS

The space system operation encompasses the satellite operations, the supporting transportation system (Space Shuttle/Tug), and the associated ground system operations. The space system will be optimized, in terms of availability and costs, by comparing alternate space systems approaches. Comparisons can also be made with competing terrestrial systems as defined under ground system operation (see Step 3). The approach to space system synthesis and cost estimates is defined in the following subsections.

### 1. STEP 2(a) - SELECT SYSTEM APPROACH(ES) AND GOALS

Space system approaches are selected for the analysis using guidance covering alternative hardware concepts for satellites and ground terminals, orbits and number of satellites, number of terminals required, and hardware design life goals. A similarity analysis is accomplished to determine what system features should be like those of similar space systems.

The spacecraft/ground terminal communications link is then defined. A tradeoff between the ground station and satellite capabilities will provide the basis for an appropriate distribution of functions between the ground station and satellite(s), thus impacting on the mission equipment functions to be performed.

### 2. STEP 2(b) - SATELLITE MISSION EQUIPMENT SELECTION

An evaluation of the mission model and space systems scenario is first made to determine if any interfaces and constraints are imposed on the space system under consideration. These constraints, if any, along with the functions to be performed by the satellite(s), influence the type of mission equipment to be considered. The various alternative technical approaches to selection of mission equipment are then reviewed, within the above-described constraints, to optimize the final selection(s). The mission equipment



configuration(s) are then generated in sufficient depth for cost estimating and system optimization purposes. The configuration information required includes equipment weights, types, sizes, performance, etc. Use is made of the mission equipment data bank, telecommunications mission equipment definition calculation forms, or the computer program used for spacecraft synthesis, to define the mission equipment.

### 3. STEP 2(c) - SELECT SPECIFIC SATELLITE INTERFACE CONCEPTS

Launch vehicle satellite transportation accommodation and traffic analyses are conducted to establish the vehicle types and traffic rate parameters necessary to deliver and support the satellite system. The analyses are performed in accordance with the procedures, rules, and assumptions described in the BRAVO User's Manual. Computer programs are not used. Logistic strategies for support of the alternative satellite maintenance approaches are considered in determining the nominal number of launches required. Launch sites supporting the satellites and launch vehicles are determined.

The number and general location of the ground terminals needed to provide coverage are determined.

### 4. STEP 2(d) - SPACECRAFT SYNTHESIS

The user spacecraft weight and design data are generated using the satellite synthesis computer program. The program uses equations for the various satellite subsystem weights. Satellites synthesized are capable of being retrieved and refurbished. Satellites are also designed for launch by the Space Shuttle and Space Tug. Satellite subsystem designs are based on historical data and modified to be optimum designs for the Shuttle fleet. The resulting computer subroutine is in modular form and operates and prints out in a mode which permits visibility of results, with the printout format organized for suitable use in the cost analysis. The printout will include a weight statement for each satellite and the related information such as orbit altitude, inclination, satellite life, modularity, electrical power, general dimensions, etc. Data flow into the spacecraft synthesis step is described in Table 2-1.

Table 2-1. BRAVO Data Flow, Satellite Synthesis  
Step 2(d)

Inputs	Drivers for BRAVO Analysis	Source
1. Satellite Identification and Orbital Parameters	Alternative Space System Approaches Selected	Satellite System Definitions
2. Attitude Control Type	Mission Equipment	Satellite Approaches
3. Pointing Accuracy	Retrieval	Mission Equipment Definition(s)
4. Mission Equipment Required	Radiated Power Power Required Weight	Mission Equipment Definition(s)
5. Satellite Packing Density		Satellite System Definitions
6. Operational Date	Funding Technology Projected Demand	Input Extension
7. Type of: Structure Propellant Electrical Power Solar Cell Orient Solar Array Paddles	Weight Constraints STS Interface Satellite Design Life	Satellite Approach

## 5. STEP 2(e) - SPACE SYSTEM COST ESTIMATING

The satellite program costs are estimated using a console-type computerized individual payload program cost model. The computer model is coded in APL language and operated from a remote console that affords simple, rapid, and routine operation. The operation requires filling out an input sheet that contains the pertinent payload design and traffic information. The input data can be fed directly into the remote console to produce an output in various formats (although the basic output is a fiscal year funding flow). Nominal inputs are set in the computer automatically when a particular input is unknown to the user.

The satellite program costs include the total payload costs, the launch vehicle direct operating costs, and the launch support costs. In addition to these costs, the associated ground systems costs, in support of the satellite system, will also be estimated to arrive at the composite cost of the entire space system.

Data flow into the space system cost estimating step is described in Table 2-2.

## 6. STEP 2(f) - SATELLITE SYSTEM OPTIMIZATION ANALYSIS

The reliability versus time characteristics of the alternative combinations of mission equipment and spacecraft devised as conceptual options for the space system are evaluated in the light of the availability goals established for the space system. The logistic strategies appropriate to support these alternatives, and consequently the launch vehicle traffic, also are evaluated and compared to the system availability goals. These resultant data are then used to select the optimum strategy and satellite system for minimum space system cost subject to meeting the availability goals.


Data flow into the satellite system optimization analysis is described in Tables 2-3 and 2-4.

Table 2-2. BRAVO Data Flow, Space System Cost Estimating, Step 2(e)

Inputs	Source
<ol style="list-style-type: none"> <li>1. Satellite Data <ol style="list-style-type: none"> <li>a. Identification</li> <li>b. Weights</li> <li>c. Describers</li> <li>d. Schedules <ol style="list-style-type: none"> <li>(1) Satellites</li> <li>(2) Revisits</li> <li>(3) Modifications</li> </ol> </li> </ol> </li> <li>2. Launch Vehicle Data <ol style="list-style-type: none"> <li>a. Identification</li> <li>b. Traffic</li> <li>c. Costs</li> </ol> </li> </ol>	<div style="text-align: center;"> <p>Satellite Synthesis</p> <p>↓</p> <p>Satellite System Definition</p> <p>↓</p> </div> <div style="text-align: center;"> <p>Satellite System Definition</p> <p>Satellite Interfaces<sup>(1)</sup></p> <p>Satellite Interfaces</p> </div>

(1) Refined by system optimization for "last pass."

Table 2-3. BRAVO Data Flow, Satellite System Optimization  
Step 2(f), Satellite System Sensitivity Analysis<sup>(1)</sup>

Inputs	Drivers For BRAVO Analysis	Source
1. Which Configuration	Satellite Redundancy Level Availability Goal	Similarity Analysis Satellite Design and Costs
2. Shuttle Failure Rate	Mission Equipment Reliability (First Application vs Second or Third Generation)	Similarity Analysis or Selected Estimates
3. Scheduled Maintenance Time	Satellite Component Wear-out Life, Satellite Design Life	Selection of Candidate Satellite Approaches
4. Fixed Launch Delays <sup>(2)</sup>	Shuttle Schedule Spare Availability	
5. Spare Activate Time	Active or Dormant Spare, Spare Transfer Time	
6. Failure Rate Multipliers <sup>(2)</sup>	Uncertainty in Parts Reliability (Failure Rate)	
7. Refurbishment/Repair Cost	R&R Level a. Components b. Modules c. Satellites  Refurb. or New Replacements	
		Satellite Program Costs

(1) Calculations performed by RISK program.

(2) Primary sensitivity parameters.

Table 2-4. BRAVO Data Flow, Satellite System Optimization  
Step 2(f), Satellite System Selection<sup>(1)</sup>

Input	Drivers for BRAVO Analysis	Source
1. Satellite System Cost	Lowest Cost at Equal Risk	From (1) Satellite Sensitivity Analysis (Output at Equal Risk) and (2) Satellite System Costing
2. Risk <sup>(2)</sup> (Between Ground System and Space System)	Space System Outages Satellite Availability Ground Link Availability	Terrestrial System Outage (Step 3 a) Satellite System Goals
3. Satellite System Risk Sensitivity	Launch Delays Failure Rate Multipliers	Satellite Sensitivity Analysis Satellite Sensitivity Analysis

(1) Tradeoff displays for selection of satellite system.

(2) Usually expressed in terms of allowable outage.

### C. STEP 3 - TERRESTRIAL SYSTEM ANALYSIS

In those cases where the intent is to compare a space-oriented system with a competing terrestrial (ground-based) system, both systems must be evaluated on an equal capability basis (e. g., performance, availability, lifetime, etc.). Thus, definition of the terrestrial system requires the use of criteria for synthesizing ground-based application capability for comparison with space systems. Estimating the costs for the terrestrial system may be approached by either of two methods, depending on the extent of detailed information available on the terrestrial system. The first method involves a detailed cost buildup, itemizing the total costs associated with development, investment, and operations. The second method involves estimating the effective terrestrial system costs or total revenues based on existing charge rates and user capacity. This second method is more appropriate for comparing existing terrestrial systems, where detailed system definition is difficult to obtain, with conceptual space systems.

### D. STEP 4 - COST-EFFECTIVENESS ANALYSIS

The objective of the cost-effectiveness analysis is to compare alternative advanced space system concepts in order to select the system alternatives which offer the greatest benefit per dollar. The selected space system concept(s) are then compared with competing terrestrial systems to evaluate the economic benefits associated with the space system(s). The cost-effectiveness analysis culminates the entire BRAVO analysis.

The cost-effectiveness analysis is performed on tabular work sheets requiring the following inputs:

- (a) Satellite system costs
  - / Mission equipment and spacecraft costs
    - R&D, investment, and operations costs
  - / Launch vehicle direct operating costs

- (b) Ground System Costs
  - / Electronics and Support Facilities Costs
    - Investment and Operating Costs
- (c) Anticipated Unit Demand Rate Schedules (Product Delivered)

The data flow into the cost-effectiveness step is described in Table 2-5.

Using the above inputs, the revenue required (in constant or current dollars as desired) to return the invested capital plus interest is computed in accordance with the following steps:

- (a) The rate of return on invested capital (interest rate) and the anticipated inflation rate are defined.
- (b) Using the previously defined interest and inflation rates, the net present value (NPV) of the cost streams is computed. The NPV of the total cost stream is broken down into discrete increments (e.g., mission equipment R&D, investment, etc.) to permit early writeoff and return of invested capital on desired portions of the space system.
- (c) The NPV of the revenue stream is equated to the NPV of the cost stream to enable computation of the required revenue. The revenue stream is defined in terms of anticipated unit demand to first calculate the unit charge rates, and then the required revenue stream as a function of the unit demand stream. The required revenue can be expressed in constant or current dollar streams by appropriate choice of economic relationships.

The analysis output is revenue streams, in constant or current dollars, to return all invested capital plus interest on invested capital. These revenue streams are then used to compare alternative advanced space systems and terrestrial systems in order to evaluate their relative economic benefits.

Interpretation of the results of the cost-effectiveness analyses and the comparisons made between (1) space system approaches and (2) space systems and ground systems are reported. Relative value of the space system approaches on an economic basis, break-even points, the influence of growth in demand, and the relative risk between space systems and ground systems carrying out the potential user's functions will be discussed.



Table 2-5. BRAVO Data Flow, Cost-Effectiveness Analysis

Inputs	Drivers for BRAVO Analysis	Source
1. Selection of Dedicated Space System Approach	Lowest Cost <sup>(1)</sup>	Dedicated Satellite System Optimization
2. Cost Streams for Space System	Dedicated System Or Shared System Or Combination of These	Dedicated Satellite Program Costs  Representative Space System Data
3. Cost Stream for Terrestrial Systems	Dedicated System Or Shared System	Terrestrial System Costs  Representative Terrestrial System Data
4. Demand Stream(s)	Initial Traffic and Growth Rate(s)	Input Extension
5. Discount Rate	Rate of Return Inflation Rate	Historical Data, Projected Historical Data

(1) At equal risk and performance.

### 3. DEFINITION OF THE PROBLEM

A BRAVO analysis starts with an interview with a potential user of space. Normally this interviewer prepares:

- (1) List of areas which could be of interest to the potential user, and
- (2) Descriptions of similar space applications and BRAVO analyses.

and briefs the potential user on the advantages of space applications and the BRAVO approach. For each potential space application of interest, the interviewer asks questions and discusses each item on the BRAVO check list with the potential user and records the resulting information. The interviewer obtains as much data and information as possible on each item. Quantitative data is preferred; relative and qualitative information is acceptable. If specific information is proprietary to the potential user, it should be so noted. If the check list item is not applicable or the information unavailable, it should be so noted.

The minimum amount of information with which an analysis can be initiated is items 1(a), 1(b), 2(a), 2(b)(5), 2(b)(6), 3(a), 4(a), or items 1(a), 1(b), 2(alternative)(a), 2(alternative)(c), 3(a), 4(a). The remainder of the data requested for this analysis then is filled in by the BRAVO team using information from similar applications to complete the problem description.

The completed problem description is reviewed with the potential user to close the loop.

BRAVO CHECK LIST  
INPUT AND PROBLEM DEFINITION

Information<sup>(1)</sup> to be covered in discussion with potential user(s) to be completed in defining each BRAVO problem. The resulting information is then the input to a BRAVO analysis.

1. SATELLITE SYSTEM OBJECTIVE

- (a) Purpose, Function Performed
- (b) Product or Service Rendered

2. SATELLITE MISSION EQUIPMENT

- (a) Type
- (b) Description
  - (1) Components List
  - (2) Component Performance
  - (3) Component Failure Rates
  - (4) Component Wear Out
  - (5) Maximum Capacity (Each Set of Mission Equipment)
  - (6) Number of Sets Required On Orbit<sup>(1)</sup>
  - (7) Location
  - (8) Spacecraft Interfaces (Power Required, Pointing Accuracy)
  - (9) Ground Terminal Interfaces (Ground Link, Data Handling and Transmission)

OR

2. (ALTERNATIVE)<sup>(2)</sup> INFORMATION SENSED OR TRANSMITTED BY THE SATELLITE

- (a) Type (Visual, IR, Voice, Digital, T.V., etc.)
- (b) Source(s) and Coverage
- (c) Peak Rates (e.g., Number of Channels, Number of Images per Day)

---

(1) Usually changes from one time period to the next.

(2) Can be used when BRAVO capability includes defining and synthesizing the mission equipment (e.g., communication links through satellite transducers, multiuser earth observations).

BRAVO CHECK LIST  
INPUT AND PROBLEM DEFINITION (CONT'D)

- (d) Duty Cycle and Utilization Factor
- (e) Tolerances and Quality
- (f) Elapsed Time for Transmission (e.g., Real Time)
- (g) Electromagnetic Regime(s)
- 3. SATELLITE INTERFACES WITH EARTH SURFACE
  - (a) Geographic Locations
  - (b) Descriptions
  - (c) Ground Link Relay
- 4. TIME (YEAR) REQUIRED, GROWTH
  - (a) Initial Operation
  - (b) Full Operation
  - (c) Growth Rate(s)
- 5. PREFERRED SPACE SYSTEM APPROACH
  - (a) Satellite Altitude and Inclination
  - (b) Satellite Features (Automated and Ground-Controlled Features)
  - (c) Outage Allowance
  - (d) Dedicated or Shared System
- 6. COMPETING TERRESTRIAL SYSTEMS
  - (a) Type of Terrestrial System
  - (b) Designation
  - (c) Outage Allowance
- 7. SYSTEM BUDGET<sup>(1)</sup>
  - (a) Buy-In Cost (Goal)
  - (b) Peak Annual Funding (Goal)

---

(1) Since the normal analysis compares space systems and ground systems, this information is not normally required. The information would be helpful in guiding the analysis, however. If there is not a competing ground system, these data are needed.

BRAVO CHECK LIST  
INPUT AND PROBLEM DEFINITION (CONT'D)

- 8. SPECIAL PROBLEMS
  - (a) Advanced State of the Art Required
    - (1) Advanced Technology
    - (2) Advanced Operating Mode
  - (b) Non-Standard STS Requirements
- 9. REFERENCES
  - (a) Related Space System References
  - (b) Related Terrestrial System References

## 4. SPACE SYSTEM ANALYSIS

### A. SYSTEM APPROACHES AND GOALS

The first objective of this activity is to define space system goals consistent with the "definition of the problem" (see Section 3).

#### 1. SYSTEM CAPACITY GOAL

The system capacity as a function of time is estimated from the information under items 2 and 4 on the BRAVO checklist (see Section 3). The capacity and peak demand curves are generally displayed on a plot (e.g., Figure 4-1). Growth is generally predicted at an annual figure (such as the 17 percent per year increase in Figure 4-1). It is recommended that at least two growth rates be analyzed for each BRAVO problem. A check is made to assure that the useful space system capacity is the same as that of the terrestrial system to which it is being compared.

#### 2. LOCATION OF GROUND LINK STATIONS AND COVERAGE GOAL

The general location of the ground areas to be served or sensed by the satellite system should be noted. The locations are described by item 3 in the BRAVO checklist. The analyst checks the location to obtain comparability with the terrestrial system areas being served. Potential changes in location of areas served as the systems grow should be considered by the analysts for both the terrestrial and space system to obtain comparability in growth of installations and equipments needed.

#### 3. COST GOALS

A goal common to all BRAVO space systems is that of minimizing costs. The criteria are:

1. Minimum system cost over the operating period
2. Minimum peak funding or expenditure rate
3. Minimum discounted cash flow.

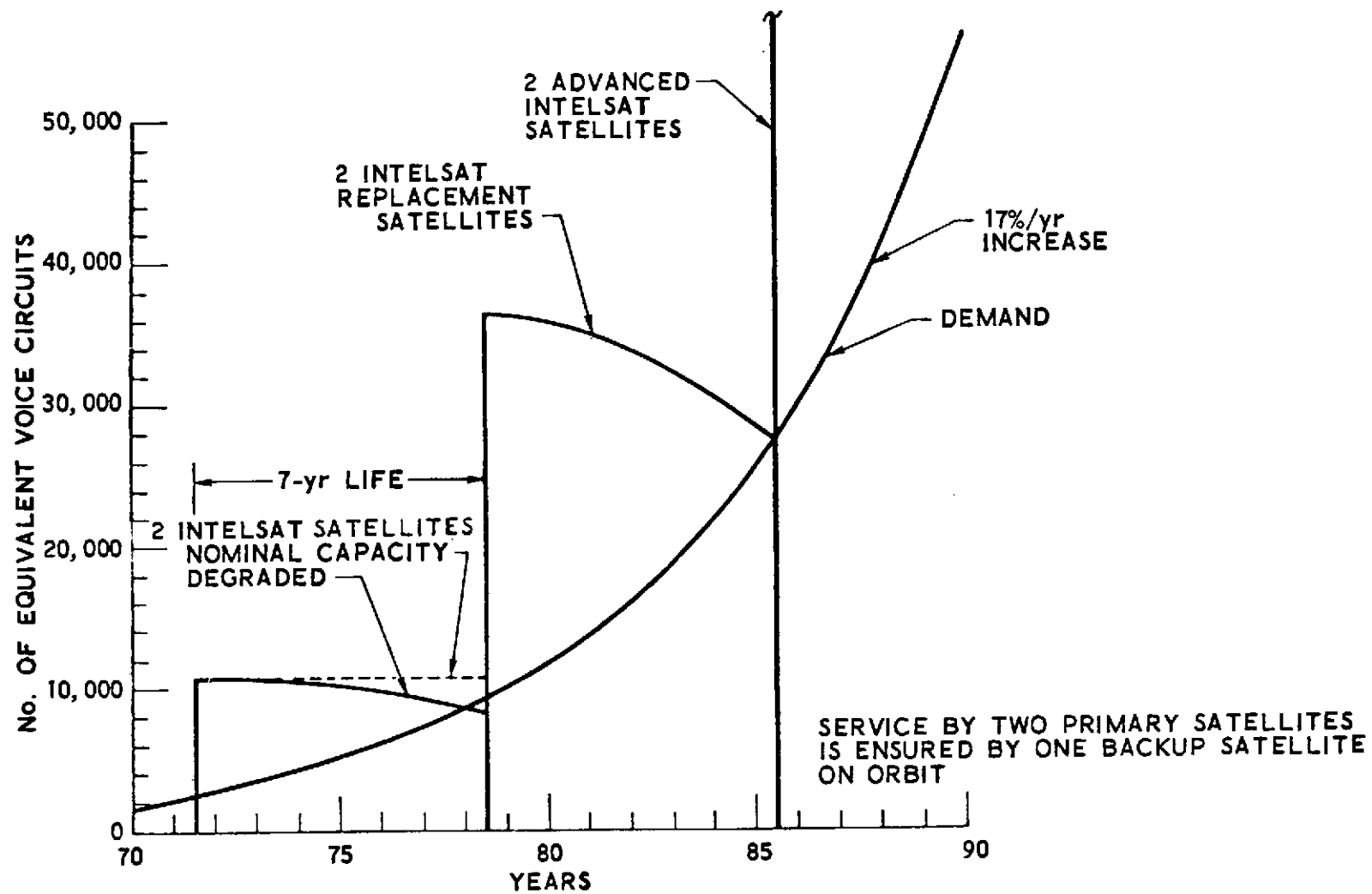


Figure 4-1. Example Demand/Capacity Data  
(Intelsats, Atlantic Basin)

The choice between alternatives in selecting the approaches to space system concepts to be considered in a particular analysis can be influenced by the cost criteria. For example, an organization with a low (e.g., one or two million dollars per year) expansion budget would generally be able to afford only a shared space system concept (i.e., space system shared with other users, e.g., leased or joint venture participation in a communication, earth observation, or other application system) as opposed to a dedicated system. It is an important criterion. If no other criteria are imposed or rationally more appropriate, the normal criteria are used: (1) the goal is to minimize total system costs over the system operating period, (2) only if total system costs are close would it be necessary to invoke the second criterion, in which case the peak annual costs (a) during system development and installation or (b) in periods of system growth (either block changes or periods of increasing installed capacity) would be used.

Cost goals (1) and (2) will generally result in minimum discounted cash flow and minimum space system revenue required.

#### 4. SYSTEM AVAILABILITY GOAL

The system availability goal is normally set by the potential space system user. For telecommunications systems, outages allowed are normally minute. Navigation systems and power systems are normally required to be very dependable. Earth observation is normally less critical and the system is useful even though out of service periodically. If no other numbers are supplied, system availability goals should be:

Communications	0.9999
Earth Observations	0.9

The outage goal is compared to the ground system outage goal and established as equal. The exceptional case may be encountered, however, when design for minimum cost criteria will result in satellite



outage which is very low (on the order of 0.001 or less) with adequate spares on the ground. This is the result of the high cost of transportation for the purpose of satellite repair. Larger outages can result if spares or transport capacity are not adequate to support rapid (e.g., two month) replacement but may not increase outages to equal the terrestrial system. This is acceptable to the analysis.

## 5. CHECKLIST FOR SYSTEM GOALS

The checklist for space system goals is:

1. System capacity
2. Location of ground link stations and coverage
3. Cost
4. System availability.

## 6. LAUNCH VEHICLE

The BRAVO analyses normally consider space systems for the period 1985 and beyond. For these the launch vehicle is normally the STS system. STS data is furnished the analyst in Section 4.D.1.c.

## 7. SATELLITE APPROACHES

### a. Shared or Dedicated Satellites

Whether a satellite system is shared by a user with other users or dedicated to his specific application makes no difference to the methodology and procedures for a BRAVO analysis. The shared/dedicated decision may be made by the potential user (see item 5, BRAVO checklist, Section 3). If no preference is expressed and there are compatible users, the analyst will normally set up two system approaches, one a dedicated system and the other a multi-user system, and make a determination of the best approach on the basis of meeting the cost criteria. A shared system will generally be lower in cost unless the "overkill" in design requirements proves to be expensive.

b. Satellite Design Approaches

The system design rules are derived from the results of analyses accomplished to date and reflect guidance most likely to result in systems optimized for lowest cost (for these normally long-term application-type systems).

1. Minimize the number of satellites required on orbit.
2. If spare satellites are needed on orbit to meet the availability requirements, the spare satellites should be active spares as opposed to dormant spares.
3. For communication satellite systems requiring high availability, component redundancy should be used. A majority of the satellite components should be doubly redundant.
4. The satellite structure should provide access to components, without the removal of other equipment. A modularized type of construction is preferred. The satellite should be retrievable. Satellite concept data estimated using the Satellite Synthesis Computer Program (see Section 4.C) are compatible with this design rule.
5. Satellites should be configured for sharing STS launches with one or more other payload visits. Compatible satellite launch dimensions and weight goals should be established.
6. Consideration should be given to configuring the satellite general arrangement so that it is possible to modify the mission equipment during the satellite's useful life, if mission equipment capacity changes are likely to be needed.
7. Frequency and extent of coverage (see goals) will normally determine satellite orbit selection and satellite locations on orbit. For continuous or frequent (more than once or twice a day) coverage, normally a synchronous altitude satellite system approach is selected. Less frequent coverage allows the consideration of low altitude satellites.

8. The satellite design mean mission duration and failure rates should be established from similarity analyses. The mean mission duration options are selected by examining other satellites of a similar design, concept application, and state of the art. Similarly, a failure rate curve is selected. If the similar satellites have detailed design data available, these data are used in the risk analysis. If not, the generalized mean mission duration and failure rate data are used.

c. Satellite Subsystem Approaches

Guidance is furnished to the analyst for selecting satellite subsystem approaches in Table 4-1.

d. Ground System Approach

Normally the least cost criterion is met by selecting a ground link station approach according to one of the following rules:

- (1) For satellites which are not communication types, select ground link approaches compatible with the STDN network (see Volume IV, Part 4, Section 6).
- (2) For trunk line communication type satellites, similar to the Intelsat system, select ground link stations similar to the Comsat network (Volume IV, Part 4, Section 7).
- (3) For other communication satellite systems, select a near-optimum, low-cost approach for the ground station size by the following procedure. The objective of this procedure is to arrive at one or two values of the figure of merit (G/T) of the ground link station which is near a low-cost system optimum. If there are many ground stations (say 100 or more), then the optimal approach is normally to select the relatively inexpensive [ 4.6-m (15-ft) diameter antenna, uncooled preamplifier ] ground station approach. If only a few (two or three) ground stations are required, a more expensive [ 9.1 to 27.4-m (30 to 90-ft) diameter antenna with cooled preamplifier ] would normally be the low-cost approach. For intermediate numbers of ground stations, lowest system cost analyses are accomplished

**Table 4-1. System and Mission Basic Inputs for  
Satellite Synthesis Program**

(May be used for first iteration analysis until user is able to identify better values.)

	Suggested Input
<u>Attitude Control Type (STABTYP)</u> (choices: single-body spin, dual-body spin, or 3-axis)	= 3-Axis
<u>Structure Type (STRTYP)</u> (choices: EXO has solar cell array paddles, or ENDO has body-mounted solar cells)	= EXO
<u>Propellant Type (PRØPTYP)</u> For auxiliary propulsion system for propulsive maneuvers too large for the reaction control system. (choices: solid, liquid, none)	= None
<u>Type of Electrical Power Generation (PWRTYP)</u> (Solar cell array is the design approach for all satellites to be synthesized.)	= Solar
<u>Type of Solar Cell Orientation (ØRINT)</u> (choices: oriented or unoriented)	= Oriented
<u>Auxiliary Propulsive Maneuver Velocity Requirement (Ft/Sec) (DVI)</u> if "none" specified in PRØPTYP	= Zero
<u>Battery Redundancy Factor (REDUN)</u>	= 0.0
<u>Solar Cell Area Packing Factor (PACKFTR)</u>	= 0.9
<u>Data Processing Element Equipment Weight (DATAPRØ)</u> (minimal to Extensive Processing) (lb)	= 50
<u>Encryption Equipment Weight (ENCØDR)</u> (if required = 25 lb)	

by analyzing the system with two alternative station approaches and choosing the lowest cost approach between them. The procedure for accomplishing this analysis is described below.

- (a) Knowing the frequency at which the down link is to operate (see Section 4.B.1), enter Figure 4-21 (page 4-92) at that frequency and select one or two antenna diameters. Normally a low-cost antenna of 4.6 to 6.1 m (15 to 20 ft) in diameter would be one option and a larger diameter antenna, about twice as expensive, would be selected unless the number of ground stations falls into the greater than 100 or two to three categories described above.
- (b) Read the antenna gain (Gain dB) from Figure 4-21 for the options to be analyzed.
- (c) Refer to page 4-90 and select the uncooled pre-amplifier approach for 4.6 or 6.1 m (15 or 20 ft) diameter antennas and either the cooled preamplifier or both the cooled and uncooled preamplifiers as alternates for larger diameter antennas.
- (d) Compute the figure of merit  $(G/T)$  for the ground link station using the formula  $G/T = G - T$  where  $G$  = antenna gain from Step (b) and  $T$  = receiving system equivalent noise temperature.
- (e) Compare the figure of merit  $G/T$  with the corresponding ground system  $G/T$  from procedures in Section 4.B.1. The same value would be used for both analyses.
- (f) The  $G/T$  value(s) are ready for use in the analysis described in Section 4.D.2.

## B. SATELLITE MISSION EQUIPMENT

### 1. TELECOMMUNICATIONS TYPE

#### a. Introduction

Procedures are presented for establishing approximate values of parameters for satellite mission equipment for communication systems employing satellites for some specific applications. The procedures have been prepared with no attempt to optimize all system parameters. Emphasis has been placed on establishing procedures for determining approximate values of the parameters for use in preliminary system economic studies; many simplifying approximations have been introduced. The satellite parameters established are dependent upon many functional criteria for each particular system. The procedures provide reference values for many of the criteria that may be used when the values are unknown; the use of these reference values may result in system parameters that are erroneous and possibly unrealizable. The satellite parameters are also sensitive to the parameters used for the communications earth station since the satellite operates in connection with the earth station. Some system tradeoff analyses can be performed by the user. This is accomplished by using a number of values for one or more parameters of interest and following the procedures to determine the influence on some other parameter(s).

A number of assumptions have been made in the preparation of the procedures which limit the extent to which they are applicable. The present procedures are limited to communication satellites in synchronous equatorial orbit with a single common parabolic reflector antenna for the up and down links, using single access and digital data with biphase shift key modulation. The procedures are also based on the assumption that the largest practicable satellite antenna will be employed; the size is limited only by the required geographical coverage (operation to the half power points has been assumed) and projected upper limits of antenna size for the operating frequencies.

#### b. Procedures

It is necessary that the user perform all additions and subtractions algebraically. Negative signs are preassigned to some worksheet entries and must be observed.

## GEOMETRY

- Lines 101 - 103 Identify geographical coverage requirements.  
Using Procedure 1<sup>(1)</sup>, determine
- Subtended angle (from satellite),  $\alpha'$ .
  - Elevation angle from each earth station,  $E_1$  and  $E_2$ .

## SATELLITE ANTENNA

Line 202 Enter satellite antenna pointing error. In the absence of other information, assume equal to attitude control accuracy; if attitude control accuracy is unknown, assume  $\pm 0.1^\circ$ . This number is the total angle; e. g., for  $\pm 0.1^\circ$ , enter  $0.2^\circ$ .

Line 204 a) Determine tentative on-axis gain using

$$G = \frac{27,000}{(\alpha)^2}$$

where  $\alpha$  is the antenna beamwidth from line 203.

b) Convert tentative on-axis gain to dB using

$$G_{dB} = 10 \log G$$

Line 205 Enter assigned frequencies on lines 205a and 205b in Hertz. If frequencies have not been assigned, tentative selections may be made from Table 4-2.

Line 206 Compute antenna diameter using

$$D = \frac{1.3 \times 10^8}{f_H} \sqrt{G}$$

$D$  = antenna diameter in meters

$f_H$  = highest radio frequency from line 205a

$G$  = tentative gain from line 204a.

---

(1) See page 4-26.

Table 4-2. Frequency Allocations for Communication Satellites

A. <u>FIXED GROUND STATIONS</u>		
<u>Downlink (a)</u>	<u>Uplink (a)</u>	<u>Comments<sup>(1)</sup></u>
2500 - 2535 MHz	2655 - 2690 MHz	Not worldwide <sup>(b)</sup>
3400 - 3700	4400 - 4700	
3700 - 4200	5925 - 6425	
	2725 - 5925	Not worldwide
7250 - 7300	7975 - 8025	Exclusive <sup>(c)</sup>
7300 - 7750	{ 7900 - 7975 8025 - 8400	
10.95 - 11.20 GHz } 11.45 - 11.70	14.00 - 14.50 GHz	
	10.95 - 11.20	Not worldwide
11.70 - 12.20		Not worldwide
12.50 - 12.75	12.50 - 12.75	Not worldwide
17.7 - 19.7	27.5 - 29.5	
19.7 - 21.2	29.5 - 31.0	Exclusive
40 - 41	50 - 51	Exclusive
102 - 105	92 - 95	Exclusive
150 - 152	140 - 142	Exclusive
220 - 230(d)		Exclusive
265 - 275(d)		Exclusive

(1) See Notes, end of this table.



Table 4-2. Frequency Allocations for Communication Satellites  
(Continued)

B. <u>MOBILE STATIONS</u>		
<u>Downlink (a)</u>	<u>Uplink (a)</u>	<u>Comments (1)</u>
161.9125 - 162.0125 MHz	157.3125 - 157.4125	Exclusive <sup>(e)</sup>
	406.0 - 406.1	Exclusive <sup>(f)</sup>
1535 - 1542.5	1636.5 - 1644	Exclusive, maritime stations
1542.5 - 1543.5	1644 - 1645	Aeronautical and maritime stations
1543.5 - 1558.5	1645 - 1660	Exclusive, aeronautical stations
43 - 48 GHz		(g)
66 - 71		(g)
95 - 101		(g)
142 - 150		(g)
190 - 200		(g)
250 - 265		(g)
C. <u>AMATEUR STATIONS</u> <sup>(h)</sup>		
7.0 - 7.1, MHz		
14.0 - 14.25		
21.0 - 21.45		
28.0 - 29.7		
144 - 146		
435 - 438		(i)
24.0 - 24.05 GHz		

(1) See Notes, end of this table.

Table 4-2. Frequency Allocations for Communication Satellites  
(Continued)

D. <u>BROADCAST SATELLITES</u> <sup>(j)</sup>	<u>Comments</u> <sup>(1)</sup>
620 - 790 MHz	Conditions for use are limited
845 - 935	Experimental use, India only
2500 - 2695	
11.7 - 12.2 GHz	
12.20 - 12.25	Not worldwide
22.5 - 23.0	Not worldwide
41 - 43	Exclusive <sup>(k)</sup>
84 - 86	Exclusive
E. <u>INTERSATELLITE LINKS</u> <sup>(1)</sup>	
54.25 - 58.2 GHz	Exclusive
59 - 64	Exclusive
105 - 130	Exclusive
170 - 182	Exclusive
185 - 190	Exclusive

(1) See Notes, end of this table.

Table 4-2. Frequency Allocations for Communication Satellites  
(Concluded)

NOTES:

This table is based on Final Acts of the World Administrative Radio Conference for Space Telecommunications, Geneva, 1971; published by the International Telecommunications Union.

- (a) The uplink and downlink frequencies are independent; however, it is convenient to list them in pairs.
- (b) Not worldwide means this is for domestic or regional systems only.
- (c) Exclusive means this is the only type of service in the band; otherwise the band is shared with other (possibly unrelated) radio services.
- (d) Uplink or downlink not specified.
- (e) For safety and emergency use only. Service not to start before 1976.
- (f) Emergency position location beacons only.
- (g) Uplink or downlink not specified. For both aeronautical and maritime stations, and shared with satellite navigation services. It was recommended that these bands later be allocated to other related series.
- (h) Shared with existing amateur radio services.
- (i) Secondary use only, must not interfere with primary services.
- (j) For broadcasting to community or individual home receivers.
- (k) It was recommended that shared use of this band with unrelated services be considered in the future.
- (l) It was recommended that shared use of these bands with unrelated services be considered in the future, because intersatellite services can be non-interfering with terrestrial services.

Compare with upper limit in Table 4-3. If diameter exceeds limit, decrease diameter and/or frequency so combination is within limits and recompute tentative high frequency gain (line 204a) using

$$G = 5.9 \times 10^{-17} D^2 F_H^2$$

D = antenna diameter in meters

$F_H$  = highest radio frequency from line 205a

Recompute line 204b if necessary.

Line 207 Compute preliminary antenna low frequency gain using

$$G_L = 20 \log \left( \frac{F_L}{F_H} \right) + G_H$$

$G_H$  = tentative highest frequency gain from line 204b

$F_L$  = lowest radio frequency from line 205b

$F_H$  = highest radio frequency from line 205a

Line 208 Choose the frequency from line 205a or 205b for the uplink. The higher of the two frequencies (line 205a) should be chosen for the uplink unless there is a reason for doing otherwise.

Line 209 The preliminary uplink gain is taken from line 204b if the high frequency is used on the uplink or from line 207 if the low frequency is used on the uplink.

Line 210 The uplink multiple factor is 0 dB for a single beam. For multiple beams, the factor is obtained from Procedure 2<sup>(1)</sup>.

Line 212 The preliminary downlink gain is taken from line 207 if the low frequency is used for the downlink or from line 204b if the high frequency is used for the downlink.

Line 213 The downlink multiple beam factor is 0 dB for a single beam. For multiple beams, the factor is obtained from Procedure 2<sup>(1)</sup>.

---

(1) See page 4-29.

Table 4-3. Antenna Upper Limit

Type	Upper Size Limit	Upper Frequency Limit
Rigid	3 Meters	$10^{11}$ Hz
	5 Meters	$5 \times 10^{10}$ Hz
Non-Rigid	15 Meters	$2 \times 10^{10}$ Hz

Line 215                      The number of transponders is 1 for a single beam. For multiple beams, it is obtained from Procedure 2<sup>(1)</sup>.

#### PRELIMINARY ESTIMATE, EARTH STATION TRANSMISSIONS

The uplink analysis in the next section requires input data on the earth station transmission characteristics. If the earth station effective isotropic radiated power (EIRP) on the earth station transmitter power and antenna gain are known, omit lines 251 through 260. If the earth station transmission characteristics are not known, this set of calculations can be used to obtain initial values.

Line 253                      Compute  $20 \log F_u$  where  $F_u$  is the uplink frequency in Hertz from line 208a.

Line 254                      Set bandwidth equal to the data rate (DR) in bits per second. (This assumes the use of non-return-to-zero bit representation.) Check frequency allocation, or Table 4-2, to verify that there is enough bandwidth available. If not, reduce data rate. Compute

$$B_{dB} = 10 \log DR$$

Line 255                      Atmospheric and rain attenuation is obtained from Procedure 3<sup>(2)</sup>. A value of 0 dB may be used if line 208a is  $8 \times 10^9$  Hertz or less.

Line 256                      The uplink carrier-to-noise ratio required by the system should be entered. If it is unknown, 20 dB is an appropriate initial value for systems known to have large transmitting earth stations; if the system uses small ground stations or if the nature of the ground stations is unknown, 15 dB is an appropriate initial value.

Line 257                       $P_T + G_T$  is the sum of the transmitter power ( $P_T$ ) in dBW and the antenna gain ( $G_T$ ) in dB of the earth station. Any combination of  $P_T$  and  $G_T$  that provides the required sum can be used. However, the remaining analysis can be performed without apportionment between  $P_T$  and  $G_T$ . If it is desired to make an apportionment, lines 258 through 260 may be used for this purpose.

---

(1) See page 4-29.

(2) See page 4-34.

Line 258                   Some value for the earth station antenna gain is entered.

Line 260                   The earth station transmitter power in dBW ( $P_T$ ) on line 259 may be converted to watts by

$$P_W = \text{antilog } \frac{P_T}{10}$$

### UPLINK

If the preliminary estimate of the earth station transmissions (lines 251 through 260) has been utilized, this uplink section should be omitted until more specific information regarding the earth station becomes known or is postulated.

If the earth station EIRP is known, enter on line 305 and omit lines 301 through 304.

Line 301                   Express earth transmitter power in dBW using

$$P_{\text{dBW}} = 10 \log P_T$$

$P_T$  = power in watts

This line may be left blank if the value of EIRP is entered on line 305.

Line 302                   Enter earth transmitting antenna gain in dB. This line may be left blank if the value of EIRP is entered on line 305.

Line 303                   The value for line 303 is obtained by adding lines 301 and 302.

Line 304                   Enter transmitter circuit losses in dB. A value of 2 dB may be used in the absence of other information.

Line 306                   Determine free space loss (SL) in dB using

$$SL = 4.1 + 20 \log F_U$$

where  $F_U$  is uplink frequency from line 208a.

Line 307 Atmospheric and rain attenuation is obtained from  
Procedure 3<sup>(1)</sup>.

Line 308 Pointing loss here is for earth station only and the  
value depends on the accuracy of the pointing system  
employed. A value of 1 dB may be used in the absence  
of other information.

Line 309 Enter polarization loss. A value of 3 dB may be used  
in the absence of other information.

Line 310 Satellite receiver circuit losses are entered here. A  
value of 1 dB may be used in the absence of other  
information.

Line 317 Receiver noise temperature is entered here. If the  
noise figure in dB ( $NF_{dB}$ ) is available it may be  
converted to temperature. First, convert the value in  
dB to a fraction (NF).

$$NF = \text{antilog } \frac{NF_{dB}}{10}$$

NF is converted to temperature by

$$T = (NF-1) 290^{\circ}K$$

In the absence of other information,  $3000^{\circ}$  may be  
used as an initial value.

Line 318 Temperature of receiver input circuits is entered.  
If unknown, use 0.

Line 319 Antenna temperature is obtained first by determining  
the factor represented by the receiving circuit losses  
(Line 310).

$$\text{Factor} = \text{antilog } \frac{- \text{losses}}{10}$$

This factor is then multiplied by  $290^{\circ}K$ .

---

(1) See page 4-34.



Line 321 Convert effective noise temperature from line 320 to dB using

$$T_{dB} = 10 \log T$$

Line 322 Set the bandwidth equal to the data rate (DR) in bits per second. (This assumes the use of non-return-to-zero bit representation.) Check frequency allocation, or Table 4-2, to verify that there is enough bandwidth available. If not, reduce data rate. Compute

$$B_{dB} = 10 \log DR$$

#### DOWNLINK

Line 401 Enter required  $E_b/N_o$ . If unknown, guidance for a limited number of cases is presented in Procedure 4<sup>(1)</sup>.

Line 402 The required margin is used to make allowances for miscellaneous losses not included in the analysis and may also be used to allow for some equipment degradation or non-optimum implementation. In the absence of other information, + 6 dB should be used for initial purposes.

Line 404 Convert  $(C/N)_U$  line 325 (or line 256 if line 325 is blank), and  $C/N$ , line 403, to ratio values using

$$C/N = \text{antilog} \frac{(C/N)_{dB}}{10}$$

Compute

$$(C/N)_D = \frac{1}{\frac{1}{C/N} - \frac{1}{(C/N)_U}}$$

Convert  $(C/N)_D$  to dB using

$$(C/N)_{DdB} = 10 \log (C/N)_D$$

---

(1) See page 4-38.

- Line 406 Enter the earth station gain-to-temperature ratio  
(G/T) in dB/°K.
- Line 407 Enter bandwidth in dB from line 322 (or line 254 if line  
322 is blank).
- Line 409 Determine free space loss using

$$SL = 4.1 + 20 \log F_D$$

where  $F_D$  is downlink frequency from line 208b.

- Line 410 The atmospheric and rain attenuation is obtained from  
Procedure 3.
- Line 411 Pointing loss is for the earth station antenna only. A  
value of 1 dB may be used in the absence of other information.
- Line 412 Enter polarization loss. A value of 3 dB may be used in  
the absence of other information.
- Line 415 Transmission circuit losses in dB is entered here. A  
value of 2 dB may be used in the absence of other  
information.
- Line 421 Convert transmit power in dBW from line 420 to watts using

$$P_{TW} = \text{antilog } \frac{P_{dBW}}{10}$$

- Line 422 Enter the satellite communications subsystem efficiency  
(power output divided by primary power input). If it is  
unknown, 0.20 may be used for a first approximation.

## GEOMETRY

101 Subtended angle (from satellite),  $\alpha'$  . . . . . \_\_\_\_\_ °  
102 a Elevation angle, transmitting station ( $E_1$ ) . . . . . \_\_\_\_\_ °  
b Elevation angle, receiving station ( $E_2$ ) . . . . . \_\_\_\_\_ °

## SATELLITE ANTENNA

201 Subtended angle from line 101 . . . . . \_\_\_\_\_ °  
202 Antenna pointing error . . . . . \_\_\_\_\_ °  
203 Antenna beamwidth. Add lines 201 and 202 . . . . . \_\_\_\_\_ °  
204 a Tentative highest frequency gain  $G$  . . . . . \_\_\_\_\_  
b Tentative highest frequency gain  $G_{dB}$  . . . . . \_\_\_\_\_ dB  
205 a Highest frequency . . . . . \_\_\_\_\_ Hz  
b Lowest frequency . . . . . \_\_\_\_\_ Hz  
206 Antenna Diameter . . . . . \_\_\_\_\_ M  
207 Preliminary low frequency gain . . . . . \_\_\_\_\_ dB  
208 a Uplink frequency . . . . . \_\_\_\_\_ Hz  
b Downlink frequency . . . . . \_\_\_\_\_ Hz  
209 Preliminary uplink gain \_\_\_\_\_ dB  
210 Uplink multiple beam factor \_\_\_\_\_ dB  
211 Uplink antenna on axis gain. Line 209 minus line 210 \_\_\_\_\_ dB  
212 Preliminary downlink gain \_\_\_\_\_ dB  
213 Downlink multiple beam factor \_\_\_\_\_ dB  
214 Downlink antenna on axis gain. Line 212 minus line 213 \_\_\_\_\_ dB  
215 Number of transponders . . . . . \_\_\_\_\_

PRELIMINARY ESTIMATE, EARTH STATION TRANSMISSIONS

251		<u>-180</u>	dBW
252	Satellite receiving antenna gain from line 211	<u>-</u>	dB
253	$20 \log F_U$ . . . . .	<u></u>	dB
254	Bandwidth (B) . . . . .	<u></u>	dB
255	Atmospheric and rain attenuation . . . . .	<u></u>	dB
256	Uplink carrier-to-noise ratio $(C/N)_U$ . . . . .	<u></u>	dB
257	$P_T + G_T$ Sum lines 251 through 256 . . . . .	<u></u>	dBW
258	Earth station antenna gain $(G_T)$ . . . . .	<u></u>	dB
259	Earth station transmitter power $(P_T)$ . . . . . line 257 minus 258	<u></u>	dBW
260	Earth station transmitter power $(P_W)$ . . . . .	<u></u>	Watts

# UPLINK

301	Earth transmitter power . . . . .	_____	dBW
302	Earth transmitting antenna gain . . . . .	_____	dB
303	Sum of line 301 and line 302 . . . . .	_____	dBW
304	Transmitter circuit losses . . . . .	_____	dB
305	Effective Isotropic Radiated Power (EIRP) line . . . . .	_____	dBW
	303 minus line 304 or input data		
306	Free space loss (SL) . . . . .	_____	dB
307	Atmospheric and rain attenuation . . . . .	_____	dB
308	Pointing loss . . . . .	_____	dB
309	Polarization loss . . . . .	_____	dB
310	Receiving circuit losses . . . . .	_____	dB
311	Total loss. Sum of lines 306 through 310 . . . . .	_____	dB
312	EIRP minus losses. Line 305 minus line 311 . . . . .	_____	dBW
313	On-axis satellite antenna gain (from line 211) _____	_____	dB
314	Off-axis loss . . . . .	3.0	dB
315	Off-axis gain. Line 313 minus line 314 . . . . .	_____	dB
316	Available carrier power. Line 312 plus line 315 . . . . .	_____	dBW
317	Receiver temperature . . . . .	_____	°K
318	Receiver input circuit temperature . . . . .	_____	°K
319	Antenna temperature . . . . .	_____	°K
320	Effective system noise temperature. Add lines 317 through 319	_____	°K
321	Effective system noise temperature . . . . .	_____	dB
322	Bandwidth (B) . . . . .	_____	dB
323		-228.6	
324	System noise power. Add lines 321 through 323 . . . . .	_____	dBW
325	(C/N) <sub>U</sub> Line 316 minus line 324 . . . . .	_____	dB

# DOWNLINK

401	$E_b/N_o$ required	_____	dB
402	Margin required	_____	dB
403	C/N Line 401 plus line 402	_____	dB
404	$(C/N)_D$	_____	dB
405		<u>-228.6</u>	
406	G/T	_____	dB/°K
407	B	_____	dB
408	Add lines 405 through 407	_____	dBW
409	Free space loss	_____	dB
410	Atmospheric and rain attenuation	_____	dB
411	Pointing loss	_____	dB
412	Polarization loss	_____	dB
413	Total propagation losses. Add Lines 409 through 412	_____	dB
414	EIRP. Add lines 404, 408 and 413.	_____	dBW
415	Transmitter circuit losses	_____	dB
416	Antenna gain plus transmitter power. Line 414. plus line 415	_____	dBW
417	On-axis satellite antenna gain. From line 214	_____	dB
418	Off-axis loss	<u>3.0</u>	dB
419	Off-axis gain. Line 417 minus line 418	_____	dB
420	Satellite transmitter power. Line 416 minus line 419	_____	dBW
421	Satellite transmitter power	_____	Watts
422	Satellite communications subsystem efficiency	_____	
423	Satellite communications subsystem primary power requirements. Line 421 divided by line 422.	_____	Watts

## PROCEDURE 1 - GEOMETRY

Identify all earth transmitting and receiving stations that will be communicating via the satellite. Plot the location of the stations on the special map provided in Section 2, Part 4 of Volume IV. The map has been constructed so that the sub-satellite is at the center of the map. The actual latitude of each station is used for the latitude of the station on the map. The longitude of each station is plotted relative to the longitude of the satellite. The longitude plotted is obtained by subtracting the longitude of the satellite from the actual longitude of the station.

If it is desired that the satellite have multiple beams, identify the stations to be served by each beam. In general, for multibeam satellites, the stations served by a beam should be relatively close to each other and separate beams should be used for stations remote to each other.

Place the elevation angle overlay on the map with the center of the overlay at the center of the map. All stations must be within the  $5^{\circ}$  elevation angle profile.

Line 1 - Count the number of geographical areas to be served by separate beams.

Line 2 - The subtended angle for each beam is obtained by using the coverage overlays and the map. There is a separate overlay for several off-nadir angles. Each overlay shows the coverage for various satellite subtended angles. Place an overlay on the map so that the center of the overlay, marked by crossed lines, is on the center of the map. Rotate the overlay so that the coverage patterns coincide with the stations of interest. Using successive trials, find the overlay which has the smallest subtended angle that includes all of the stations to be served by the beam. Interpolation can be used between overlays as well as between the coverage patterns on an overlay. If a beam serves a single station, the subtended angle is  $0^{\circ}$ .

Repeat the process for each beam. Of the subtended angles determined, the largest is entered on line 2 and line 101 of the main procedure.

Select a pair of stations that will be communicating with each other for the link analysis. The stations chosen need not be served by the same beam. Consideration should be given to the selection so that it represents the worst case; this is necessary for the satellite transponder to be properly sized. If the worst case is not obvious, the link analysis should be performed for each station pair which might be the worst case. The downlink is usually

more important than the uplink in identifying the worst case. For a given data rate and radio frequency, the worst case for either the uplink or the downlink is generally associated with earth stations that are farthest from the subsatellite point. However, if the earth stations have different capabilities or different link requirements, low earth station G/T, high required  $E_b/N_0$  and high required margin contribute to the downlink worst case; low earth station transmitter power and/or antenna gain contribute to the uplink worst case. For multibeam satellites, stations that are farthest from the center of the total geographical area covered by the satellite can contribute to the worst case for both the up and down links.

Lines 3 and 4 - Place the elevation angle overlay on the map and determine the elevation angle of transmitting station ( $E_1$ ) and the elevation angle of the receiving station ( $E_2$ ).  $E_1$  is also entered on line 102a of the main procedure and  $E_2$  is also entered on line 102b of the main procedure.

The remainder of this procedure is concerned with establishing parameters for satellites with multiple beams and need not be completed for satellites with single beams.

Lines 5 and 6 - Using the coverage overlays, find the smallest coverage pattern that includes all of the stations to be served by all the beams. The antenna axis off-nadir angle is identified by the overlay used. Read the antenna axis azimuth with the overlay in place so that all of the stations are within the coverage pattern.

Lines 7 and 8 - Using the coverage overlays, find the smallest coverage pattern that includes all of the stations to be served by the beam serving the transmitting station. The off-nadir angle is identified by the overlay used. The azimuth is obtained with the overlay in place so that all of the stations served by the beam are within the coverage pattern.

Lines 9 and 10 - Repeat the process given for lines 7 and 8 for the receiving station.



PROCEDURE I - GEOMETRY

1. Number of geographical areas N ..... \_\_\_\_\_
2. Subtended angle  $\alpha'$  ..... \_\_\_\_\_ o
3. Elevation angle, transmitting station  $E_1$  ..... \_\_\_\_\_ o
4. Elevation angle, receiving station  $E_2$  ..... \_\_\_\_\_ o
5. Antenna axis off-nadir angle  $ON_o$  ..... \_\_\_\_\_ o
6. Antenna axis azimuth  $AZ_o$  ..... \_\_\_\_\_ o
7. Uplink beam off-nadir angle  $ON_1$  ..... \_\_\_\_\_ o
8. Uplink beam azimuth  $AZ_1$  ..... \_\_\_\_\_ o
9. Downlink beam off-nadir angle  $ON_2$  ..... \_\_\_\_\_ o
10. Downlink beam azimuth  $AZ_2$  ..... \_\_\_\_\_ o

## PROCEDURE 2 - MULTIPLE BEAM FACTOR

This procedure provides the means of establishing an estimate of antenna gain degradation due to the use of multiple beams. It is based on a focal length-to-diameter ratio of 0.5 and an aperture illumination taper of 10 dB, which are considered satisfactory for general sizing purposes. However, if there is a reason to use other values for these parameters, other methods must be employed for accurate results. The procedure is also based on the assumption that the beamwidth of the satellite antenna is the same for both the uplink and downlink. This will provide reasonable results for the usual situation with the uplink and downlink frequencies relatively close to each other. If the uplink and downlink frequencies are widely separated, the procedure should be changed for accurate results.

Line 1 - Compute the scan angle

$$\psi = \cos^{-1} \left[ \sin ON_1 \sin ON_0 \cos (AZ_1 - AZ_0) + \cos ON_1 \cos ON_0 \right]$$

where  $ON_0$ ,  $AZ_0$ ,  $ON_1$ , and  $AZ_1$  are from lines 5, 6, 7, and 8 of Procedure 1.

Line 2 - Divide the scan angle on line 1 by the antenna beamwidth from the main procedure line 203.

Line 3 - The scan angle from line 2 is used with Figure 4-2 to determine the scan loss.

Line 4a - The number of geographical areas served appears on line 1 of Procedure 1. Determine the maximum number of these areas which contain stations that will communicate via the satellite simultaneously -- this is, the number of antenna beams.

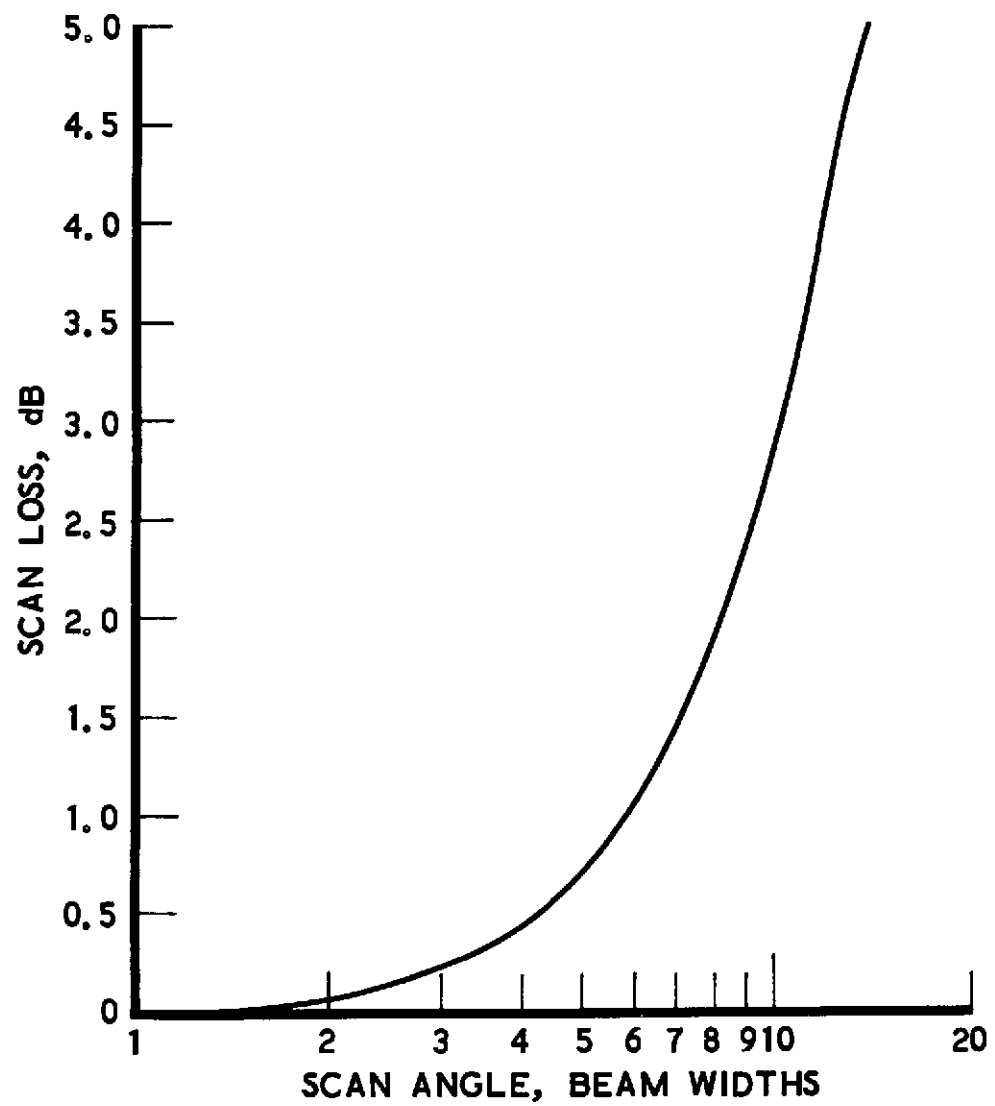


Figure 4-2. Scan Loss

Line 4 b - Determine the maximum number of areas that contain stations that will be receiving simultaneously -- this is the number of transponders. Also enter on line 215 of the main procedure.

Line 5 - Compute

$$\frac{d}{D} = \frac{3 \times 10^8 \sqrt{n}}{D F_U}$$

n from line 4a

D from main procedure line 206

F<sub>U</sub> from main procedure line 208a

Line 6 - The value of d/D from line 5 is used with Figure 4-3 to determine the blockage loss.

Line 7 - The uplink multiple beam factor is obtained by adding the values on lines 3 and 6. This value is also entered in main procedure line 210.

Line 21 - Compute the scan angle

$$\psi = \cos^{-1} \left[ \sin ON_2 \sin ON_0 \cos (AZ_2 - AZ_0) + \cos ON_2 \cos ON_0 \right]$$

where ON<sub>0</sub>, AZ<sub>0</sub>, ON<sub>2</sub>, and ON<sub>2</sub> are from lines 5, 6, 9, and 10 of Procedure 1.

Line 22 - Divide the scan angle on line 21 by the antenna beamwidth from the main procedure line 203.

Line 23 - The scan angle from line 22 is used with Figure 4-2 to determine the scan loss.

Line 25 - The downlink multiple beam factor is obtained by adding the values on lines 23 and 24. This value is also entered on main procedure line 213.

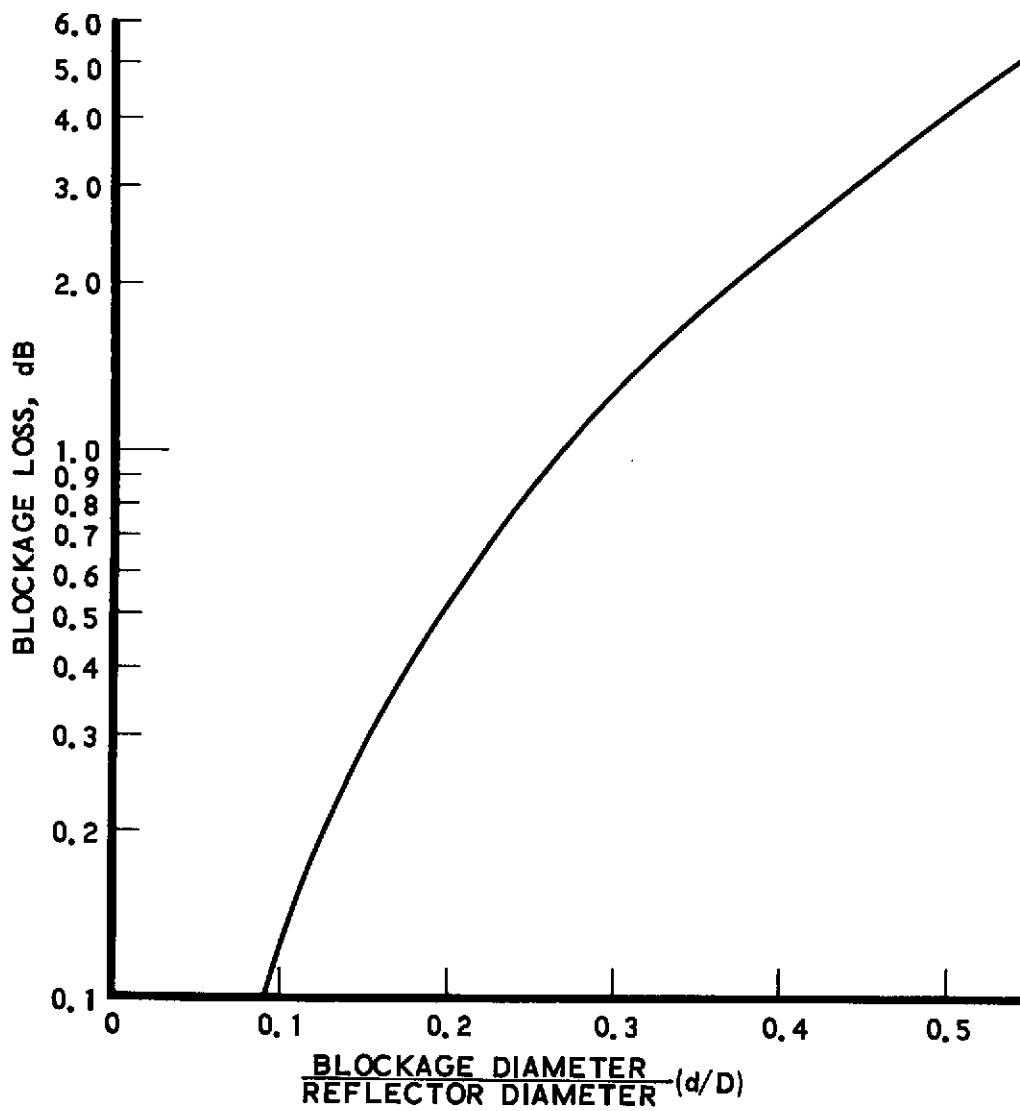


Figure 4-3. Blockage Loss

## PROCEDURE 2 -- MULTIPLE BEAM FACTOR

### UPLINK

- |   |       |    |
|---|-------|----|
| 1. Scan angle - degrees . . . . .                       | _____ | o  |
| 2. Scan angle - beamwidths . . . . .                    | _____ |    |
| 3. Scan loss . . . . .                                  | _____ | dB |
| 4a. Number of antenna beams, n . . . . .                | _____ |    |
| b. Number of transponders . . . . .                     | _____ |    |
| 5. Blockage diameter ÷ reflector diameter d/D . . . . . | _____ |    |
| 6. Blockage loss . . . . .                              | _____ | dB |
| 7. Uplink multiple beam factor                          | _____ | dB |
| Line 3 plus Line 6 . . . . .                            | _____ |    |

### DOWNLINK

- |   |       |    |
|---|-------|----|
| 21. Scan angle - degrees . . . . .      | _____ | o  |
| 22. Scan angle - beamwidths . . . . .   | _____ |    |
| 23. Scan loss . . . . .                 | _____ | dB |
| 24. Blockage loss from Line 5 . . . . . | _____ | dB |
| 25. Downlink multiple beam factor       |       |    |
| Line 23 plus Line 24 . . . . .          | _____ | dB |

### PROCEDURE 3 - ATMOSPHERIC AND RAIN ATTENUATION

This procedure provides estimates of atmospheric and rain attenuation that might be encountered and is representative of the best information available at this time. The amount of attenuation that must be included is dependent upon the availability requirement. If transmission can be limited to the time that there is no rain, the attenuation is obtained from Figure 4-4 for attenuation of 20 dB or less, or from Figure 4-5 for attenuation greater than 20 dB; however, the presence of clouds or fog will introduce some errors which are undefined at this time. If transmissions must occur during rain, Figures 4-6 through 4-8 are used in accordance with the following table. The peak rainfall rate during which transmissions must be accomplished should be used for the locations being considered. The availability, which is based on assumed rainfall statistics, is an alternate and less accurate method.

<u>Peak Rate (mm/hr)</u>	<u>Availability of uplink or downlink Due to Attenuation</u>	<u>Figure</u>
3.05	0.99	4-6
15.20	0.999	4-7
61.00	0.9999	4-8

To obtain the uplink atmospheric and rain attenuation for line 255 or line 307, divide the uplink frequency from line 208a by  $10^9$  to convert the frequency to GHz. Enter the appropriate figure with the uplink frequency in GHz and the transmitting station elevation angle from line 102a.

To obtain the downlink atmospheric and rain attenuation for line 410, divide the downlink frequency from line 208b by  $10^9$  to convert the frequency to GHz. Enter the appropriate figure with the downlink frequency in GHz and the receiving station elevation angle from line 102b.

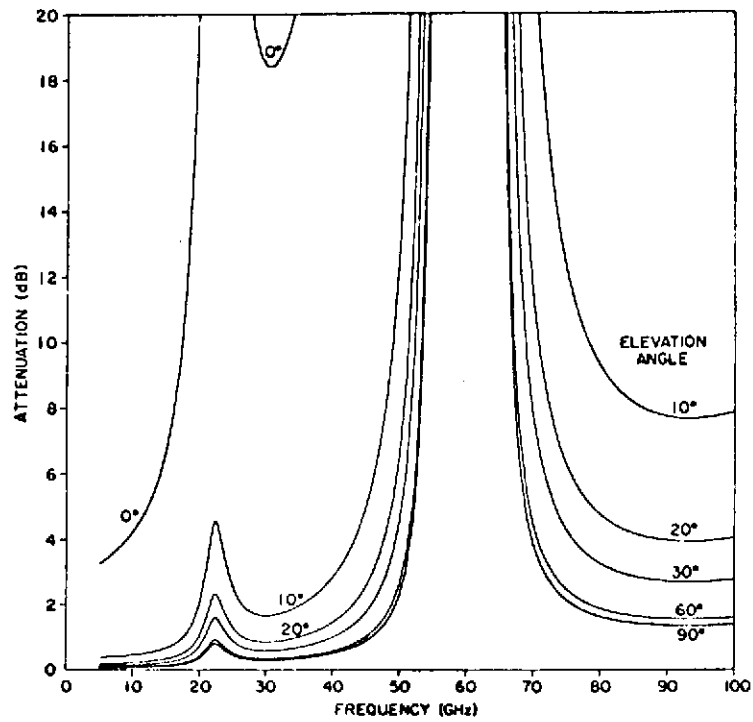


Figure 4-4. Atmospheric Attenuation

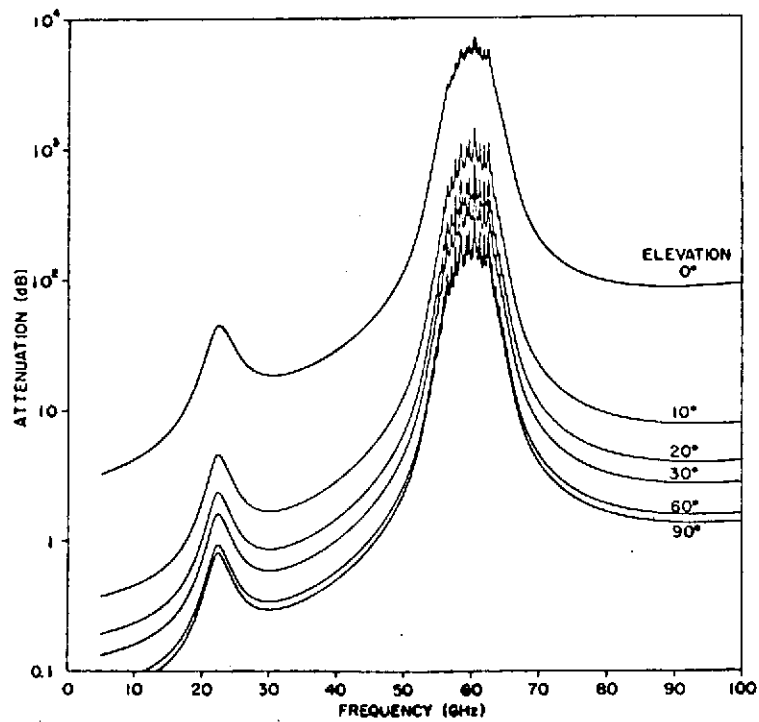


Figure 4-5. Atmospheric Attenuation



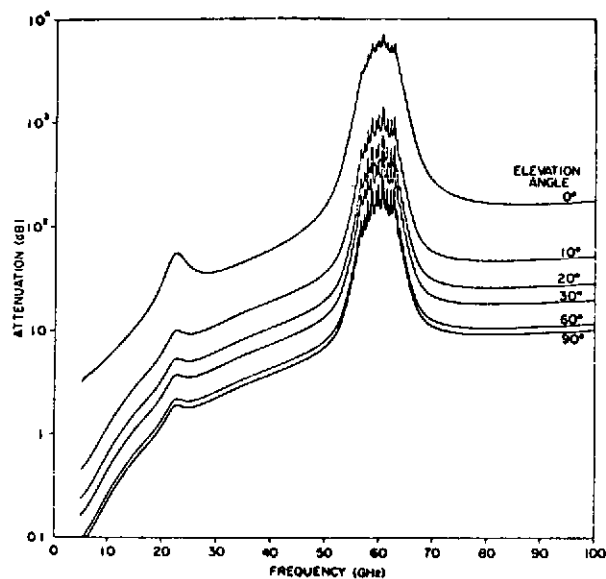


Figure 4-6. Atmospheric and Rain Attenuation  
(Link Availability: 0.99) 3.05 mm/hr

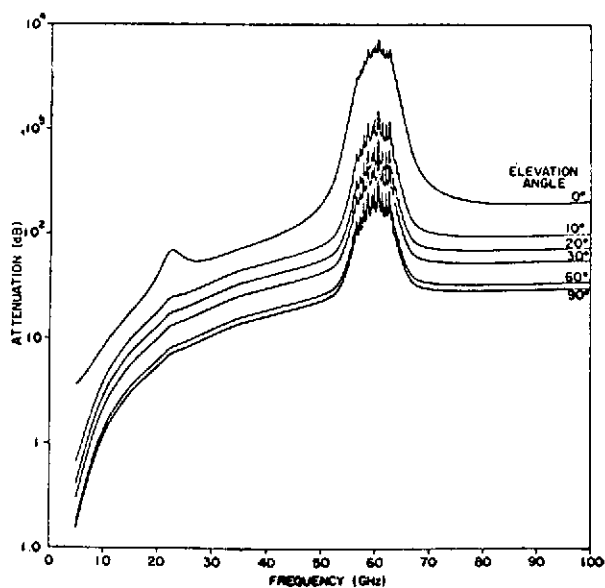


Figure 4-7. Atmospheric and Rain Attenuation  
(Link Availability: 0.999) 15.2 mm/hr

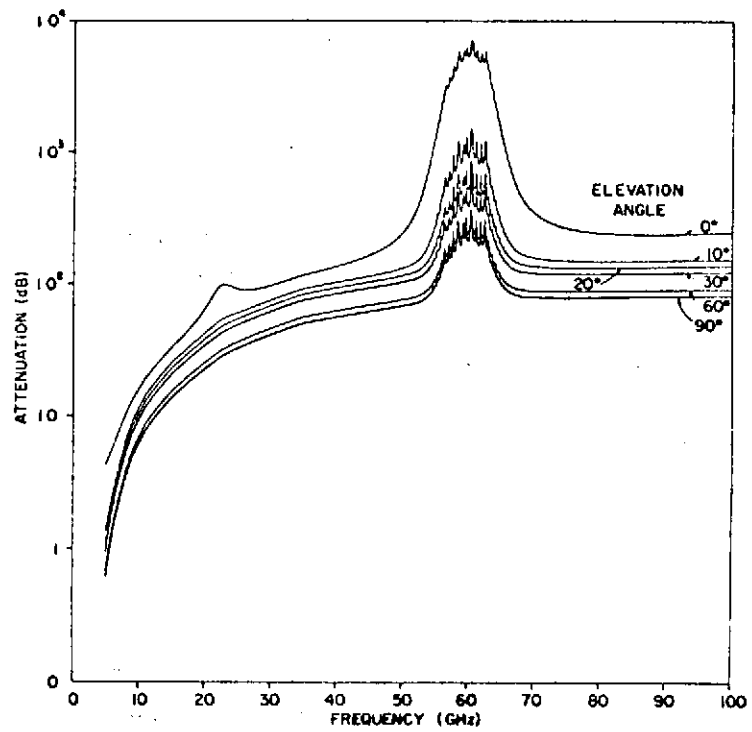


Figure 4-8. Atmospheric and Rain Attenuation  
(Link Availability: 0.9999) 61.0 mm/hr

If the atmospheric and rain attenuation is very severe, the impact on the communications system parameters can be quite serious. The impact can be alleviated through the use of two stations. Ideally, the two stations would be far enough apart so that a single cell of intense rain would not degrade reception of both simultaneously, and yet close enough so that both would not be degraded simultaneously by two different cells of intense rain. Methods for calculating the improvement that results from multiple station operation are beyond the scope of this procedure.

#### PROCEDURE 4 - REQUIRED $E_b/N_0$

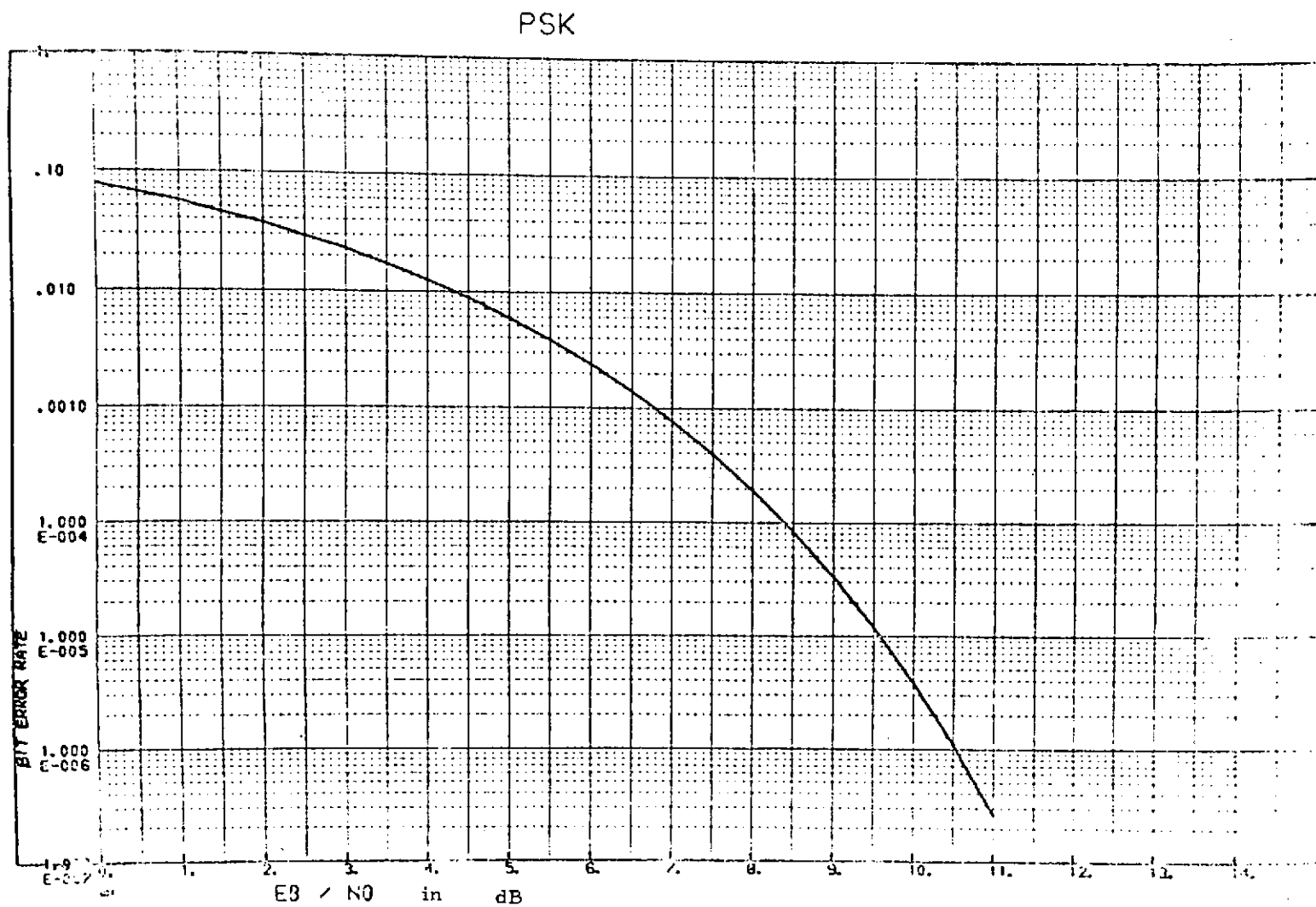
The required value of  $E_b/N_0$  for an uncoded signal is obtained from Figure 4-9 for the required bit error rate.

The bit error rate performance of a radio link can be enhanced through the use of digital codes. The variety and form of the codes are nearly limitless. A few selected examples are included in this procedure. All codes included in this procedure are convolutional and nonsystematic. While codes can be generated at a variety of rates, those included in this procedure are all at rate 1/2. The bit error rate performance is based on the use of Viterbi decoding with 32 bit paths (comparable to 32 bit memory).

For hard decoding decisions, the required  $E_b/N_0$  is obtained by referring to Figure 4-10 and using the required bit error rate and constraint length of the code (K).

For soft decoding decisions employing eight levels of quantization, the required  $E_b/N_0$  is obtained by using the solid curves in Figures 4-11a or 4-11b along with the required bit error rate and constraint length of the code (K).

Following selection of a code, the bandwidth on line 322 (or line 254 if line 322 is blank) of the main procedure must be divided by the code rate; that is the bandwidth that would actually be occupied. Check frequency allocation, or Table 4-2, to verify that there is enough bandwidth available. If not, use a higher rate code or reduce the data rate. If the data rate is reduced, all the procedures and worksheets should be reviewed and modified as necessary to reflect the lower data rate.

Figure 4-9.  $E_b/N_0$  vs Bit Error Rate

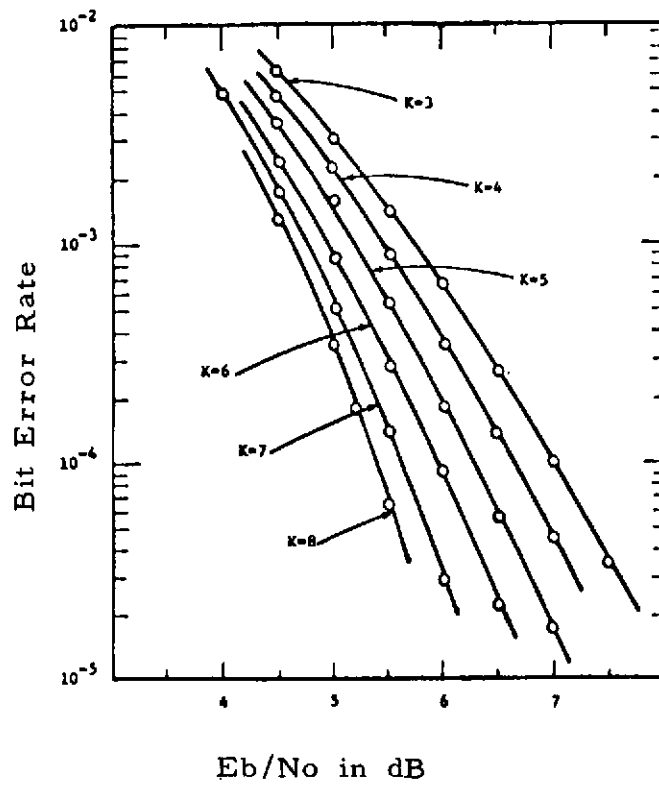


Figure 4-10. Hard Decisions, Rate 1/2 Convolutional Code  
Viterbi Decoding, 32-Bit Paths

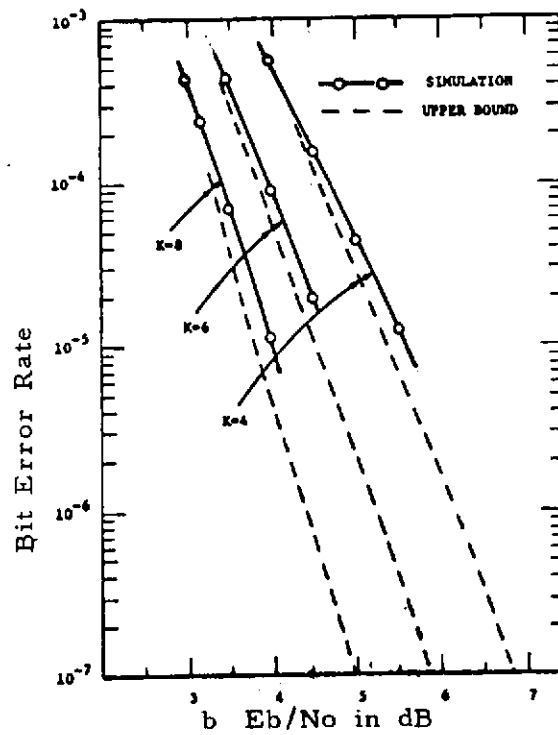
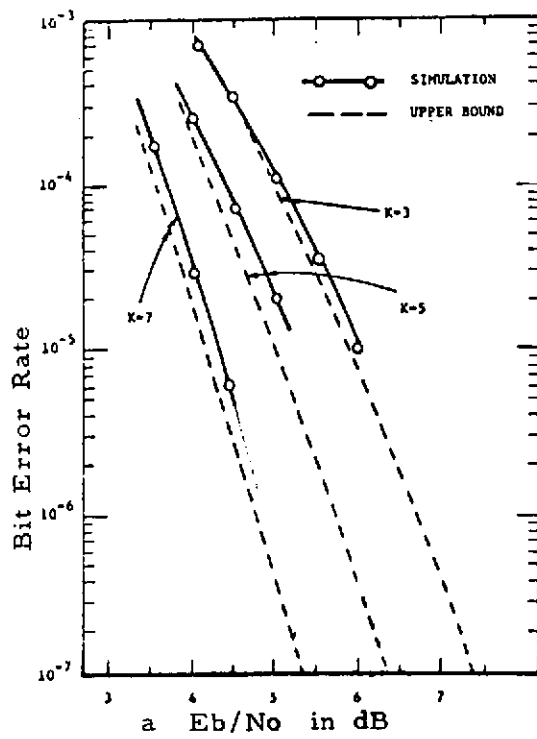
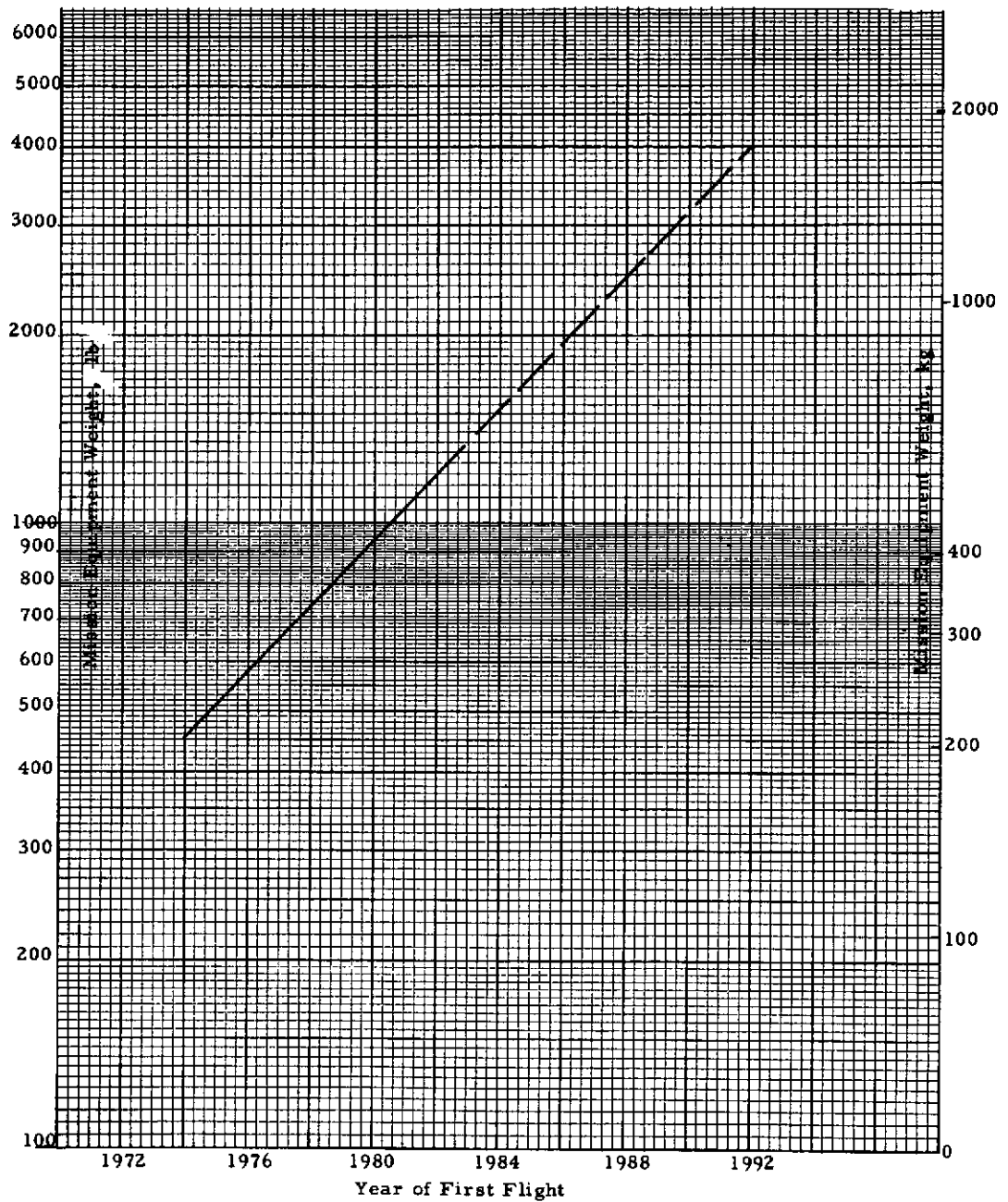


Figure 4-11. Soft Decisions, Rate 1/2 Convolutional Code  
Viterbi Decoding, 8-Level Quantization,  
32-Bit Paths

## 2. EARTH OBSERVATION TYPE

The weight and power required for earth observation from a low-altitude, multiuser, automated earth observation satellite is obtained from the curves in this section. The mission equipment weight depends on the year of initial operation (see Figure 4-12). The mission equipment power required is related to the mission equipment weight (see Figure 4-13). Mission equipment after 1980 can include active (future) sensors (e.g., radar and lidar) as well as the passive types of sensors. Multiuser earth observation satellites are assumed to embody scanning and multiple band radiometers, spectrometers, and mappers as well as advanced sensors.



**Figure 4-12. Multi-User Earth Observation Satellite Mission Equipment Weight Estimating Relationship**



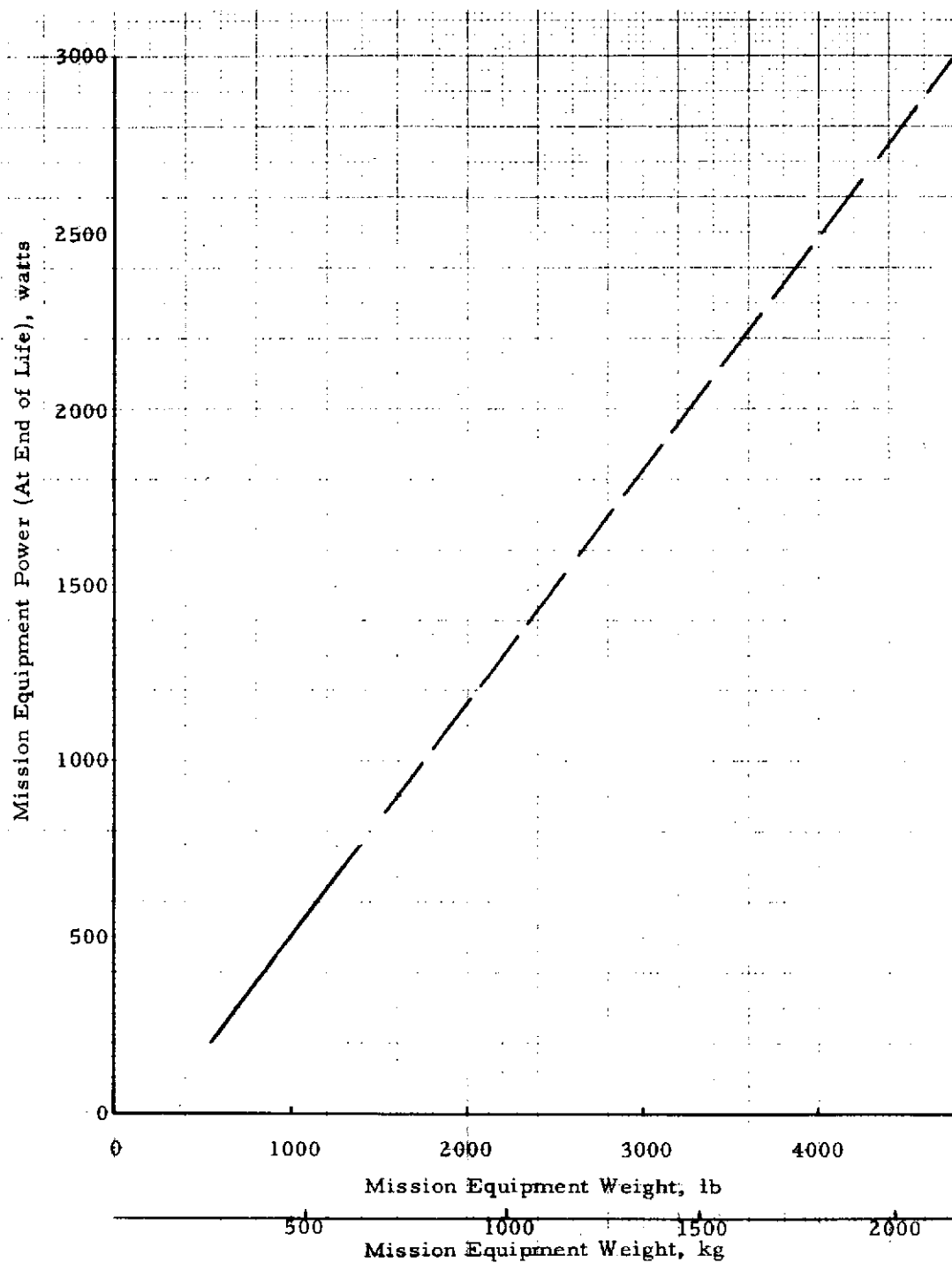


Figure 4-13. Multi-User Earth Observation Satellite Mission Equipment Power Estimating Relationship

## C. SATELLITE SYNTHESIS

### 1. INTRODUCTION

The objective of the BRAVO Satellite Synthesis Program is to generate satellite weights and other satellite data in a short time with minimal input requirements. The basic inputs, such as orbit altitude, if not known by the system user, may be estimated from data in the Satellite System Definition section of this manual.

The synthesis program may also be readily used to perform sensitivity and optimization studies of spacecraft as a function of such basic parameters as electrical power producing capability.

This portion of the manual includes a description of the synthesis program, a typical deck setup and operating instructions, the procedure for using the workbook associated with this manual, and a typical example. Also included is a discussion of the derivation of the program, the logic used, and the development of the equations used therein. The applicable limits of the program are identified.

### 2. SYNTHESIS PROGRAM OPERATION

#### a. Program Description

The Satellite Synthesis Program described herein has been developed for use in the BRAVO and other NASA payload studies in the FORTRAN IV language and is usable on various computers. Many of the variables in the program are automatically accommodated by the use of internal equations instead of requiring the operator to input values from graphs. An example of this is the mean mission duration variable. By inputting a specific value, or series of values, for this parameter the correct influence is automatically produced. Insertion of the satellite type on the input sheet (i. e., communication, navigation, or observation) will result in the automatic selection of appropriate equation constants within the computer program. Iterative subroutines are also automatic in the program.

The computer develops subsystem weights and other pertinent data as functions of the input parameters. It uses these computations to generate the structure weight and size. Finally, the weight and length of the adapter structure is computed. The printout itemizes these data. A typical printout is included in Volume IV, Part 4 of this Final Report.

The synthesis program and the equations used therein were developed in English rather than metric units and are presented here in those units.

The development of the subsystem weight equations, Shuttle application factors, and program logic is described in Paragraph 4 of this section of the Manual.

b. Instructions

The user operates the program by inputting basic data on one of the input sheets supplied in the workbook. These data are used by a programmer familiar with the synthesis program to prepare the eight data input cards. These are placed in the card stack as shown in Figure 4-14 and the program is operated.

If the synthesis program is not operating in a service area available to the user, a programmer experienced in the use of FORTRAN IV language may set up the program using the listing included in the printout in Volume IV, Part 4 of this Final Report.

A step-by-step procedure for operating the program and the workbook is supplied in the following paragraphs.

3. PROGRAM OPERATING PROCEDURE

The steps outlined below will permit the user to operate the synthesis program successfully. The workbook provided as Volume IV, Part 3 of this Final Report is used as part of this procedure.

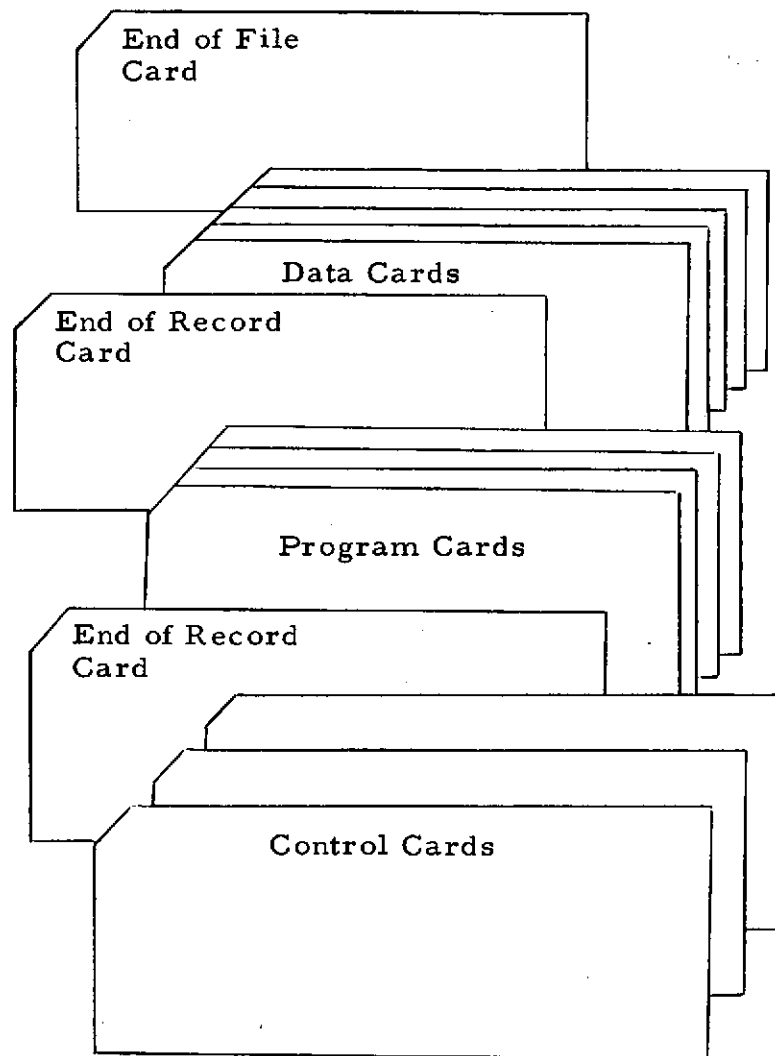


Figure 4-14. Typical Computer Card Stack

a. Basic Inputs

Approximately 40 inputs are required to operate the program. These include basic items such as orbit altitude and inclination, mission equipment weight, volume and electrical power requirements, pointing accuracy, etc.

b. Input Sources

Ideally the user will obtain satellite synthesis inputs from the "Satellite System Definitions" and "Mission Equipment Definitions" steps accomplished earlier in this analysis. Suggested values suitable for preliminary operation of the program are, however, included in this report in Table 4-4 for consideration by the user in case other values have not been specified. Unusual mission equipment data could, of course, be determined with the assistance of an expert familiar with the development of that equipment.

c. Input Sheets

Copies of an input sheet identified as the "Satellite Synthesis Program Input Sheet" are supplied in the Workbook (Volume IV, Part 3) of this Final Report. All of the basic inputs must be listed on this sheet for successful program operation.

The required locations for the basic input data on the input sheets are identified on Figure 4-15 in computer symbol form. Sample input values are shown on Figure 4-16 which is typical of a form ready for key punching. The sample input values are consistent with the results shown in the sample printout provided in Volume IV, Part 4, of this report. A symbol list is given in Table 4-5. Blank copies of the form in Figure 4-15 are supplied in the Workbook. As with most computer input sheets, the input data must be carefully written as shown in the sample sheet. Numbers must be placed within the correct 10-column section and must include a decimal point. Letter symbols must be written and placed exactly as shown as these words are used as tests (i.e., start in left side of section).

Table 4-4. System and Mission Basic Inputs for  
Satellite Synthesis Program

Note: May be used for first iteration analysis until user is able to identify better values.

	Suggested Input
<u>Attitude Control Type (STABTYP)</u> (Choices: single-body spin, dual-body spin or 3-axis)	= 3-Axis
<u>Structure Type (STRTYP)</u> (Choices: EXO has solar cell array paddles or ENDO has body-mounted solar cells)	= EXO
<u>Propellant Type (PRØPTYP)</u> For auxiliary propulsion system for propulsive maneuvers too large for the reaction control system. (Choices: solid, liquid, none)	= None
<u>Type of Electrical Power Generation (PWR TYP)</u> (Solar cell array is the design approach for all satellites to be synthesized.)	= Solar
<u>Type of Solar Cell Orientation (ØRINT)</u> (Choices: oriented or unoriented)	= Oriented
<u>Auxiliary Propulsive Maneuver Velocity Requirement (ft/sec) (DV1)</u> (If "none" specified in PRØPTYP)	= Zero
<u>Type of ACS Propellant (ACSPROP)</u> (Choices: hot gas or cold gas)	= Hot Gas
<u>Number of Tape Recorders in CDPI (XNTAPRC)</u>	= As Required
<u>Number of Down Links in CDPI (XNDNLNK)</u>	= 1.0

Table 4-4. System and Mission Basic Inputs for  
Satellite Synthesis Program (Cont'd)

	Suggested Input
<u>Minimum Mean Mission Duration (Years) (XMMDMIN)</u>	
<u>Mean Mission Duration Increment (Years) (XMMDINC)</u>	
<u>Maximum Mean Mission Duration (Years) (XMMDMAX)</u>	
(For a single mean mission duration (MMD), enter the desired value in all three locations. For a range of MMD, enter the minimum MMD in XMMDMIN, the increment in XMMDINC, and the maximum MMD in XMMDMAX. The satellites used in the data base for the weight equation derivation had an average MMD of about 2.5 years which is equivalent to a design life of about 3 years.)	
<u>Battery Redundancy Factor (REDUN)</u>	= 0.0 <sup>(1)</sup>
<u>Solar Cell Area Packing Factor (PACKFTR)</u>	= 0.9
<u>Data Processing Element Equipment Weight (DATAPRØ)</u> (Minimal to extensive processing) (lb)	= 0 to 100 <sup>(2)</sup>
<u>Encryption Equipment Weight (ENCØDR)</u> (if required = 25 lb)	= 0.0

- (1) Equations provide a nominal battery weight. If, however, additional redundancy is required, this factor should be used. (+50 percent redundant = 0.5)
- (2) This weight is in addition to the 50 lb normally estimated for the telemetry and communications element.



PROGRAMMER _____										KEYPUNCHED _____										VERIFIED _____										DATE _____										PAGE _____ OF _____																								
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65
CODE										ORBAPØ										ORBPER										ORBINC										PBATF										STABTYP										1				
XMIS PWR										PNTACC										DEN										XIOC										STRTYP										PROPTYP										2				
PWRTYP										S										ORINT										ACSPROP										XMEI										TYPE										3				
A										B										C										CFI										PADTYP										DVI										4				
XMMDMIN										XMMDINC										XMMDMAX										R										REDUN										PROGRAM										5				
XMØDMIN										XMØDINC										XMØDMAX										PACKFTR										D										T										6				
XNDNLNK										XNTAPRC										DATAPRØ										ENCØDR										XNXPOND										PWRXPON										7				
ANTDI AM										COMFREQ										E										F										G										H										8				

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Figure 4-15. Satellite Synthesis Program Computer Input Sheet - Symbols





PROGRAMMER _____										KEYPUNCHED _____										VERIFIED _____										DATE _____										PAGE _____ OF _____																								
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65
SEQ - 1										1 9 0 0 0.										1 9 0 0 0.										0.										1.										3 - A X I S										SEQ - 1				
1 7 5.										0. 2 0										4.										1 9 8 0										EX Ø										LIQ U I D										SEQ - 2				
S Ø L A R										0.										Ø R I										C Ø L D G A S										2 9 4.										N A V										SEQ - 3				
0.										0.										0.										0.										R I G I D										0.										SEQ - 4				
2.										0. 5										2. 0										0.										0. 0										B R A V Ø										SEQ - 5				
1 2.										1. 0										1 2.										0. 9										0.										0.										SEQ - 6				
2.										2.										1 5 0.										0.										0.										0.										SEQ - 7				
0.										0.										0.										0.										0.										0.										SEQ - 8				

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Figure 4-16. Satellite Synthesis Program Computer Input Sheet - Sample

Table 4-5. Input Sheet Symbol Identification

(Note: limit name to seven (7) characters)

<u>CARD 1 (Line 63)</u>	
CØDE	= Satellite name - Case (SEO-1) free choice name
ØRBAPØ	= Orbit apogee altitude (nmi)
ØRBPER	= Orbit perigee altitude (nmi)
ØRBINC	= Orbit inclination (deg)
PBATF	= Fraction of total power provided by batteries during eclipse
STABTYP	= Attitude control type (3-axis, spin, 2-spin <sup>(1)</sup> )
<u>CARD 2</u>	
XMISPPWR	= Mission equipment power required (watts)
PNTACC	= Pointing accuracy (deg)
DEN	= Satellite packing density (lb/ft <sup>3</sup> )
XIØC	= Operational date (year)
STRTYP	= Structure type (endo or exo)
PRØPTYP	= Propellant type (liquid or solid)
<u>CARD 3</u>	
PWRTYP	= Type of electrical power generation (solar)
S	= Not used
ØRINT	= Type of solar cell orientation [ oriented (ORI) or fixed (UNORI)]
ACSPRØP	= Type of attitude control propellant (cold gas or hot gas)
XME1	= Mission equipment weight (lb)
TYPE	= Mission type (COM., NAV., OBS.)

(1) Denotes dual spin satellite

Table 4-5. Input Sheet Symbol Identification (Cont'd)

<u>CARD 4</u>		
A	=	Not used
B	=	Not used
C	=	Not used
CF1	=	Contingency factor
PADTYP	=	Type of solar array (rigid or flex)
DV1	=	Apogee motor velocity requirement (ft/sec)
<hr/>		
<u>CARD 5</u>		
XMMDMIN	=	Minimum mean mission duration (years)
XMMDINC	=	Mean mission duration increment (years)
XMMDMAX	=	Maximum mean mission duration (years)
R	=	Not used
REDUN	=	Battery redundancy factor (0.0)
PRØGRAM	=	Name of program (BRAVO)
<hr/>		
<u>CARD 6</u>		
XMØDMIN	=	Minimum number of modules
XMØDINC	=	Module increment
XMØDMAX	=	Maximum number of modules
PACKFTR	=	Solar cell area packing factor (fraction) (0.9)
D	=	Not used
T	=	Not used

Table 4-5. Input Sheet Symbol Identification (Cont'd)

<u>CARD 7</u>	
XNDNLNK	= Number of down links in CDPI
XNTAPRC	= Number of tape recorders in CDPI
DATAPRØ	= Data processing element equipment weight (lb)
ENCØDR	= Encryption equipment weight (lb)
XNXPØND	= Number of transponders
PWRXPØN	= Individual transponder output (watts)
<u>CARD 8</u>	
ANTDIAM	= Antenna diameter (ft)
CØMFREQ	= Communication frequency (GHz)
E	= Not used
F	= Not used
G	= Not used
H	= Not used

d. Data Input Cards

An experienced programmer transfers the data from the input sheets to the data cards and places them in the stack as shown in Figure 4-14. The program is then operated. The user need not be involved in this operation.

e. Results

The results of the computation are tabulated at the end of the printout and are readable without the assistance of the programmer. A sample printout which reflects the data shown on the input sheet, Figure 4-16, is provided in Volume IV, Part 4, of this Final Report. The user evaluates the results and then, if desired, re-operates the program with different values using new input sheets. Results may be plotted to depict trends. The selected data are now available for input to the Satellite Cost Analysis Program.

f. Limits

The parameters used in the Satellite Synthesis Program reflect experience of existing satellite programs and extending values for them beyond these delineated limits will reduce the accuracy of the results.

Satellite weight = not over 11,340 kg (25,000 lb)

Electrical power = not more than 5000 watts

Design life = not to exceed 10 years

Pointing accuracy = not less than 0.01 deg

Transponder power output = not more than 300 watts each

Antenna diameter ( $D_a$ , feet)  $\left\{ \begin{array}{l} F^{0.5} D_a^{2.5} = \text{not more than } 10,000 \\ \text{Antenna frequency (F, GHz)} \end{array} \right.$

Also, when items are incremented (such as XMMD on Card 5 and XMOD on Card 6), the following rules must be observed:

- (1) XMMDMIN (value may be zero)
- (2) XMMDINC (value must not be zero)
- (3) XMMDMAX (value as required)

If only one MMD period (2 years) is required (as in the example of Figure 4-16) use:

- (1) XMMDMIN = 2.0 years
- (2) XMMDINC = 0.5 years
- (3) XMMDMAX = 2.0 years

The system used is that the computer adds the incremental time (0.5) to the minimum time (2.0) for a total of 2.5. It compares this to the maximum time (2.0) and since the 2.5 year total is greater than the maximum time (2.0 years) required, the program goes on to the next case. If, however, the incremental time (XMMDINC) is inadvertently entered as zero, then the sum of the minimum time (2.0), plus the increment (0.0), will never be longer than the maximum (2.0) and the computer will continue to perform the same calculation until a built-in time limit is reached which will terminate the run.

It should also be noted that a normal communication satellite will have either mission equipment (XME1, Card 3) or an antenna (ANTDIAM, Card 7) and a transponder (XNXPOND, Card 7), but not both.

Also note, the satellite packing density factor (DEN1) on Card 2. The program contains equations which will select a normal packing density ranging from a high of  $176 \text{ kg/m}^3$  ( $11 \text{ lb/ft}^3$ ) for a small [450 kg (1000 lb)] satellite to a low of  $32 \text{ kg/m}^3$  ( $2 \text{ lb/ft}^3$ ) for a 4500 kg (10,000 lb) (or greater) satellite. If these equations are to be used, the DEN1 factor must be zero. If, however, the operator wishes to bypass the equations in the program, he can do so by inserting the packing density of his choice in the DEN1 position on Card 2.

#### 4. SATELLITE SYNTHESIS COMPUTER PROGRAM

A brief discussion of the BRAVO Satellite Synthesis Computer Program is provided herein for reference. The user is not required to be familiar with this development to operate the program.

##### a. Derivation

The Satellite Synthesis Program has been prepared for the purpose of determining candidate satellite vehicle physical data as required for the BRAVO User's Manual. The program is in FORTRAN IV language for use on various computers. Every effort was made to minimize input data and auxiliary computations by the user and therefore the iteration subroutines and graphic data are automatic in the program. Once the user has access to the synthesis program in his service area, he is only required to input basic data on an input sheet.

The synthesis program contains satellite subsystem weight equations, also referred to as weight-estimating relationships (WERs), prepared as functions of basic influencing parameters. These equations are explained subsequently.

The sequence of the synthesis program operation is shown herein in a highly simplified flow diagram, Figure 4-17. The overall program for the BRAVO User's Manual is shown in a diagram in a prior section of this report. The interaction of the synthesis and other programs is shown on that diagram.

##### b. Equations

The synthesis program contains basic equations for estimating the weight of current expendable satellite subsystems for which much data were available for analysis. Factors are used with these equations to modify the satellite for Shuttle application. These equations are described in the following paragraphs. The satellite synthesis program and the equations used therein were developed in English rather than metric units.

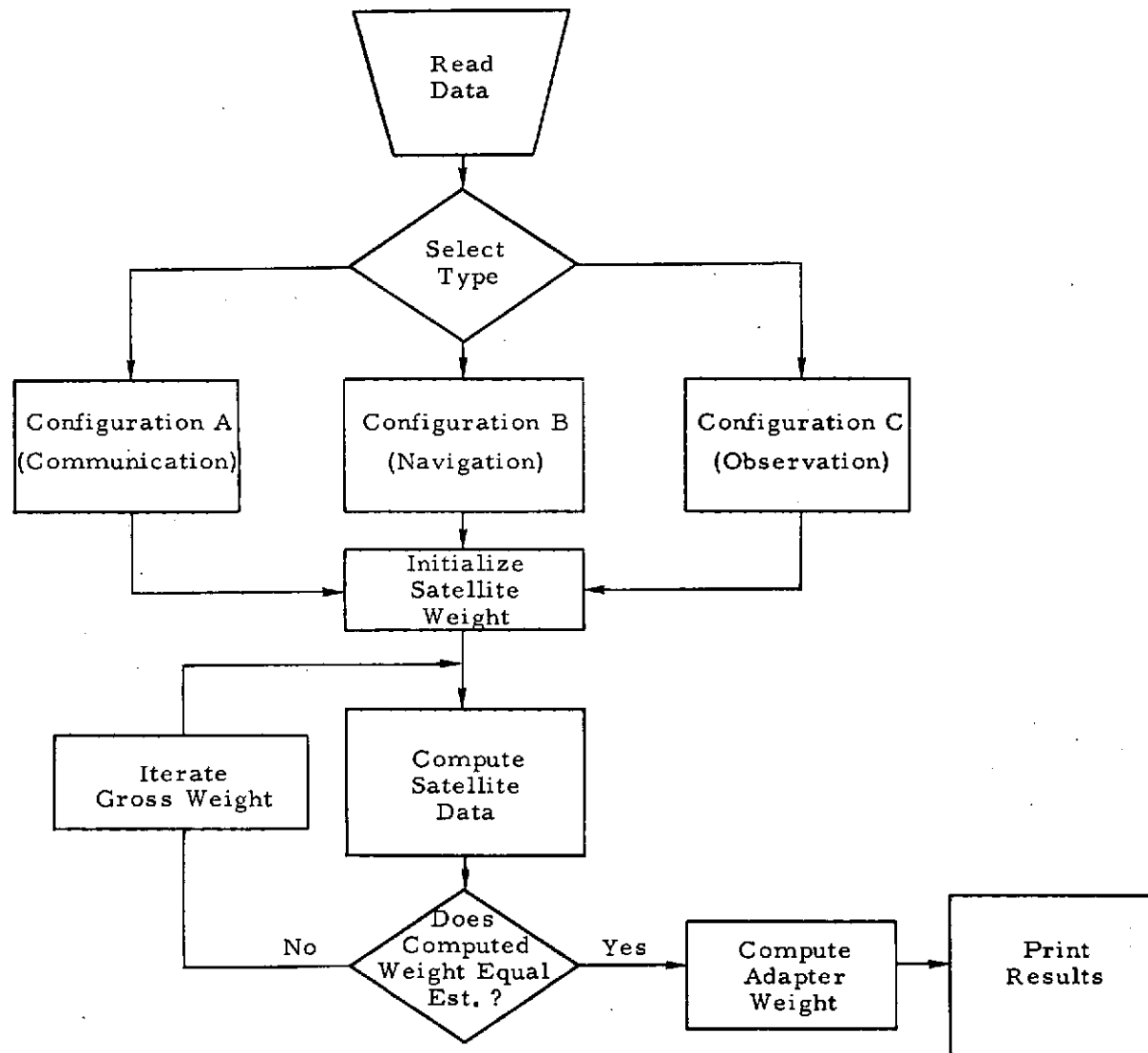


Figure 4-17. Satellite Synthesis Computer Program Flow Diagram



## (1) Basic Equations

The basic subsystem weight equations were developed by establishing and correlating actual satellite data with a theoretical model. Data were correlated using a regression analysis computer routine. Parameters which had a low influence on the resulting subsystem weight were deleted from the equations for simplification.

The basic weight equation for each subsystem is listed here. The symbols used in the equation are included. Letter symbols are used in the equation development. The FORTRAN IV symbols used in the computer program are provided in Volume IV, Part 4, of this report and are not necessary for these derivations. Two typical subsystem graphs are included to show the correlation of actual data with the equations. These are for structure, Figure 4-18, and for the communication antenna, Figure 4-19.

### a. Structure

$$W_s = K_\rho \left[ (W_c)^{0.9} (L/D)^{0.24} \right]^{1.096}$$

where:

- $K_\rho$  = Density coefficient
  - = 0.218 for satellites with body-mounted solar cells (endo)
  - = 0.129 for satellites with extendable solar panels (exo)
- $W_c$  = Weight of satellite contents (lb)
- $L/D$  = Satellite length-to-diameter ratio.

### b. Thermal Control (Passive)

$$W_{tc} = 0.025 W_{sc}$$

where:

- $W_{sc}$  = Spacecraft weight (lb).

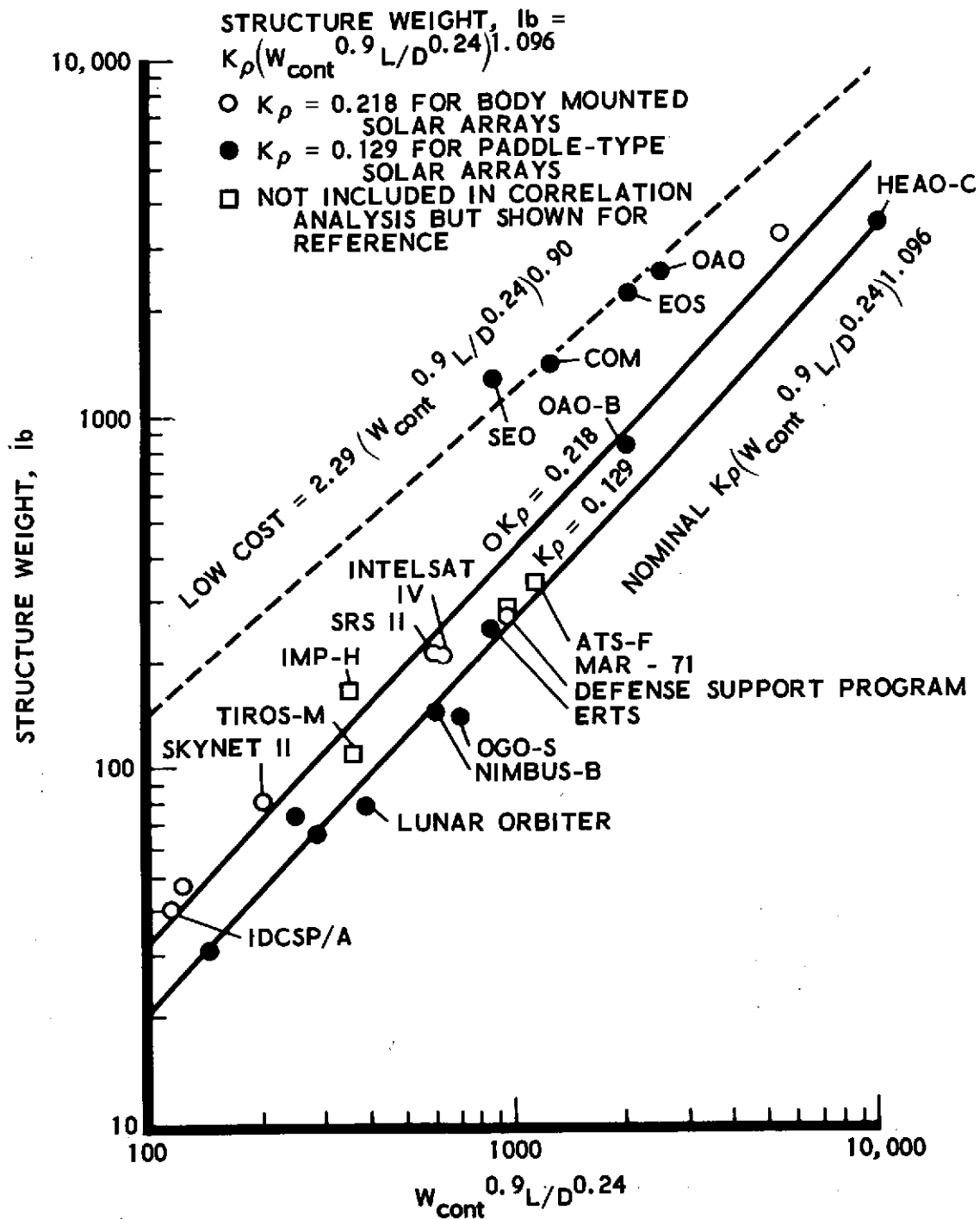


Figure 4-18. Structure Weight Correlation

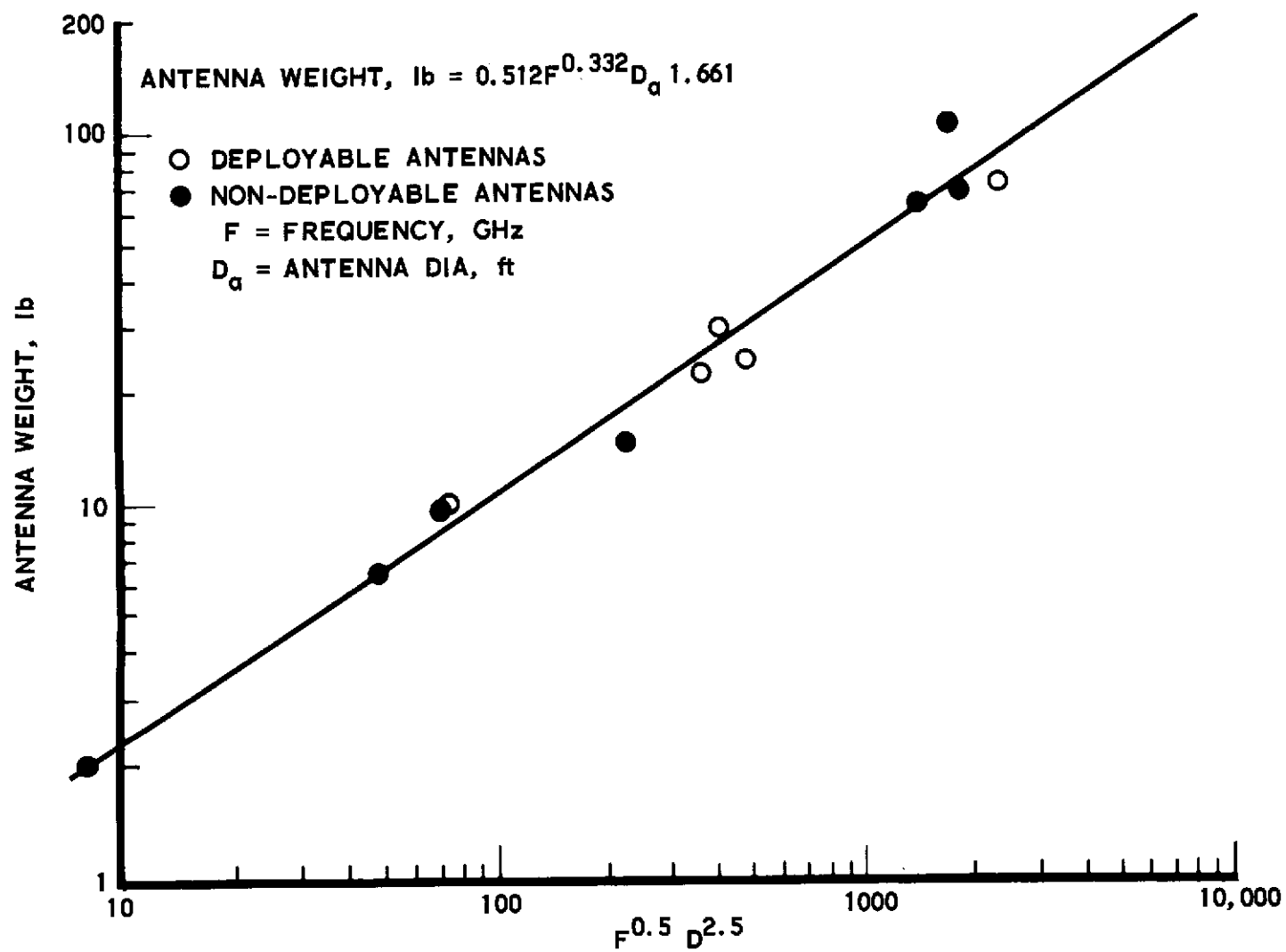


Figure 4-19. Communication Antenna Weight Correlation

c. Electrical - Batteries

$$W_{\text{bat}} = (0.454 + 0.037 \text{ Life}) (1.018 - 3.628 \bar{H} \times 10^{-5}) T_e P_{\text{bat}} \\ (1 + R) \left[ 0.99^{\text{IOC}-1970} \right]$$

where:

Life = Design life of spacecraft, years

$\bar{H}$  = Average orbit altitude, nmi

$T_e^*$  = Time in eclipse, hours

$P_{\text{bat}}$  = Battery power required during eclipse, watts

R = Redundancy factor (e.g., if R = 0.5, redundancy = 50%)

IOC = Year of initial operational capability

d. Solar Arrays

For orbit altitudes less than geosynchronous,

Body Mounted:

$$W_{\text{sa}} = \frac{P_{\text{sa}} (2.67 - 0.39 \log_{10} \bar{H})}{(3.38 - 0.3 \log_{10} \text{Life})} \left( \frac{0.38}{\text{PF}} + 0.35 K_{\text{va}} \right) \left[ 0.99^{\text{IOC}-1960} \right]$$

Oriented Paddles, Rigid Substrate:

$$W_{\text{sa}} = \frac{P_{\text{sa}} (2.67 - 0.39 \log_{10} \bar{H})}{(9 - \log_{10} \text{Life})} \left( \frac{1}{\text{PF}} + 0.35 K_{\text{va}} \right) \left[ 0.99^{\text{IOC}-1960} \right]$$

Oriented Paddles, Flexible Substrate:

$$W_{\text{sa}} = \frac{P_{\text{sa}} (2.67 - 0.39 \log_{10} \bar{H})}{(9 - \log_{10} \text{Life})} \left( \frac{0.2}{\text{PF}} + 0.35 K_{\text{va}} \right) \left[ 0.99^{\text{IOC}-1970} \right]$$

---

\* Computed in program as function of orbit altitude.

For geosynchronous orbit altitudes.

Body Mounted:

$$W_{sa} = \frac{P_{sa} (2.67 - 0.39 \log_{10} \bar{H})}{(3.19 - 0.47 \log_{10} \text{Life})} \left( \frac{0.38}{PF} + 0.35 \right) \left[ 0.99^{(\text{IOC}-1960)} \right]$$

Oriented Paddles Rigid Substrate:

$$W_{sa} = \frac{P_{sa} (2.67 - 0.39 \log_{10} \bar{H})}{(8.6 - 1.4 \log_{10} \text{Life})} \left( \frac{1}{PF} + 0.35 \right) \left[ 0.99^{(\text{IOC}-1960)} \right]$$

Oriented Paddles Flexible Substrate:

$$W_{sa} = \frac{P_{sa} (2.67 - 0.39 \log_{10} \bar{H})}{(8.6 - 1.4 \log_{10} \text{Life})} \left( \frac{0.2}{PF} + 0.35 \right) \left[ 0.99^{(\text{IOC}-1970)} \right]$$

where:

- $P_{sa}$  = Total solar array power requirement, watts
- $\bar{H}$  = Average orbit altitude, nmi
- Life = Design life of spacecraft, years
- PF = Ratio of solar cell-to-substrate areas
- $K_{va}$  = Two if orbit is in the Van Allen belts, one if not.

e. Electrical Harness

$$W_h = 0.013 W_{eq}^{1.31} V_{sc}^{0.16}$$

where:

- $W_{eq}$  = Weight of power consuming equipment (mission equipment plus CDPI plus G&N), lb
- $V_{sc}$  = Volume of spacecraft, cubic feet

f. Electrical - Power Conditioning

$$W_{pc} = 3.11 P_{sa}^{0.333}$$

where:

$P_{sa}$  = Total solar array power requirement, watts

g. Guidance, Navigation, and Stabilization

Three-Axis Control:

$$W_{gns} = 1.11 \frac{W_{sc}^{0.537}}{PA^{0.243}}$$

Dual Spinner:

$$W_{gns} = 3.54 \frac{W_{sc}^{0.417}}{PA^{0.107}}$$

Spinner:

$$W_{gns} = 1.79 \frac{W_{sc}^{0.35}}{PA^{0.39}}$$

where:

$W_{sc}$  = Spacecraft weight on orbit, lb

PA = Pointing accuracy, deg

h. Reaction Control Propellants

$$W_p = K_{wp} W_{sc}^{0.769} \text{ Life}^{0.2}$$

where:

$K_{wp}^*$  = 0.348 for hot gas (hydrazene), 1.040 for cold gas.

---

\* Normally used for attitude control with low-level  $\Delta V$ . For Shuttle-launched payloads, only one-third of this weight is used since maneuvers such as emplacement are performed by the Tug or Shuttle.

i. Reaction Control Hardware

$$\text{Hot Gas: } W_{rc} = 0.128 W_p + 0.063 W_{sc}^{0.725}$$

$$\text{Cold Gas: } W_{rc} = 1.16 W_p^{0.846} + 1.37 W_{sc}^{0.269}$$

where:

$W_p$  = Propellant weight, lb

$W_{sc}$  = Spacecraft weight on orbit, lb

j. Communications, Data Processing, and Instrumentation

$$W_{cdpi} = 50 + 5 (\bar{H}^{0.1}) (N_{dl} - 1) + 15 N_{tr} + DP + ENC$$

where:

$\bar{H}$  = Average orbit altitude, nmi

$N_{dl}$  = Number of down links

$N_{tr}$  = Number of tape recorders

$DP^*$  = Data processing element of subsystem weight, lb

$ENC^*$  = Encryption subsystem weight, lb

k. Mission Equipment - Communications

$$\text{Communications mission equipment weight} = W_{tr} + W_a$$

Transponder:<sup>(1)</sup>

$$W_{tr} = N_{xp} (0.09 P_{xpo} - 3.13 N_{xp} + 64)$$

Parabolic Antenna:<sup>(1)</sup>

$$W_a = 0.512 D_a^{1.661} F^{0.332}$$

---

\* Estimated values given in Table 4-4.

(1) Including associated equipments

where:

- $N_{xp}$  = Number of transponders  
 $P_{xpo}$  = Individual transponder output (i. e., to antenna), watts  
 $D_a$  = Parabolic antenna diameter, ft  
 $F$  = Parabolic antenna frequency, GHz

The mission equipment weight for all satellites is an input to the program (Card 3, item 5, XME1). Therefore if the total communications mission equipment weight is accounted for by the two equations noted above (Transponder and Parabolic Antenna), then XME1 should have a value of zero.

It should also be noted that no MMD factor is applied to mission equipment to account for redundancy since it is assumed that the mission equipment weight is the same for all mission durations. Therefore care must be taken to include a large enough mission equipment weight to account for the desired level of redundancy at the maximum mean mission duration.

$$\begin{aligned}
 &\text{Adapter Weight} \\
 t &= \left\{ \frac{W_g \left( 3 + \frac{4\ell_g}{D} \right)}{2\pi E + \left[ 9 \left( \frac{2t}{D} \right)^{0.6} + 0.16 \left( \frac{D}{2\ell_a} \right)^{1.3} \left( \frac{2t}{D} \right)^{0.3} \right]} \right\}^{0.5} \\
 W_{\text{adapt}} &= 1.5 \pi D \ell_a t \rho
 \end{aligned}$$

where:

- $W_g$  = Load on adapter, lb  
 $D$  = Adapter diameter (average), ft  
 $\ell_a$  = Adapter length, ft  
 $\ell_g$  = Centroid of adapter load to centroid of adapter, ft  
 $t$  = Adapter shell thickness, ft  
 $E$  = Modulus of elasticity  
 $\rho$  = Material density, lb/ft<sup>3</sup>



## (2) Shuttle Application Factors

The use of the basic equations just described will permit synthesis of current expendable, or reference, satellites. To modify the satellite designs for Shuttle use, Shuttle application factors are applied to the subsystem equations within the program. They include the effects of on-orbit maintenance and varying the mean mission duration. Another set of factors is included, based on a study done by the Lockheed Missile and Space Company (LMSC), which adapts the satellite design to a low-cost, modular configuration.

### a. Mean Mission Duration Factors

Preliminary factors for varying the mean mission duration effects on the satellite are based upon analysis performed in The Aerospace Corporation's Reliability Department. In that analysis, the increases in components in various subsystems required for various MMD values were determined. Weights were calculated for these values and converted to factors in equation form as shown in the following listing. The factors are automatically determined within the program.

<u>Subsystem</u>	<u>Factor</u>
Guidance and Navigation	= $0.1334 \text{ MMD} + 0.6665$
CDPI	= $0.1814 \text{ MMD} + 0.5465$
Electrical Power	= $0.0594 \text{ MMD} + 0.8515$
Attitude Control Inerts	= $0.1918 \text{ MMD} + 0.5205$

Notes: MMD value input as years

Reference subsystem weights are for 2.5 year MMD

### b. On-Orbit Maintenance Factors

On-orbit maintenance of satellites is assumed to be accomplished by the use of modularity. Design studies were performed at LMSC and Aerospace to establish configurations of typical satellites

in modular form. Weight data from these studies were derived and converted to the factors listed below, as shown in Figure 4-20.

<u>Subsystem</u>	<u>Factor</u>
Structure	
Less than 8 modules	$= 0.1143 N_m + 0.8857$
More than 8 modules	$= 0.0875 N_m + 1.10$
Electrical Distribution and Conditioning	$= 19.7 N_m$
Thermal Protection	$= 1.10 W_{tc}$

where:

$N_m$  = Number of modules per spacecraft

$W_{tc}$  = Weight of reference satellite thermal protection subsystem.

c. Low-Cost Modular Factors

Studies conducted by LMSC for NASA presented the effects of adding low-cost and modularity features to satellite designs in combined form. The following factors were developed and included in the synthesis program. In this case different factors are used for each of the three satellite types except for the structure subsystem.

Subsystem	Satellite Type		
	Comm.	Navigation	Observation
Thermal Control	1.33	1.36	1.36
Guidance & Navigation	1.79	1.07	1.08
Attitude Control	1.28	1.28*	2.80**
CDPI	0.75	1.16	0.64
Electrical Power	1.45	1.81	2.40
Mission Equipment	1.00	1.47	1.00
Structure	***	***	***

\* Hot Gas

\*\* Cold Gas

\*\*\* Same as factors in Section (2) b (at top of this page).

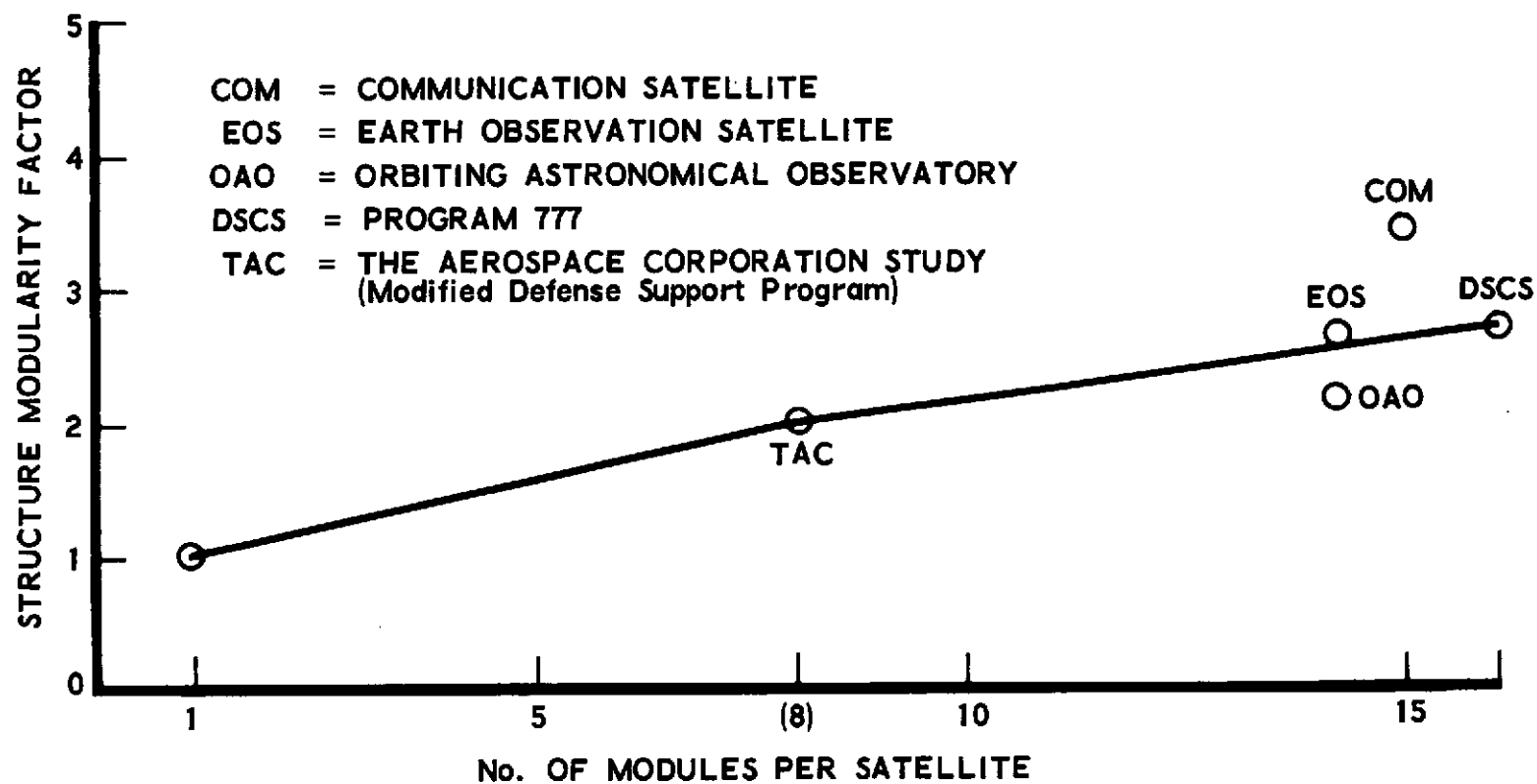


Figure 4-20. Structure Modularity Factor

D. SATELLITE INTERFACE CONCEPTS

1. SATELLITE TRANSPORTATION ACCOMMODATION

a. Introduction

The satellite accommodation by the STS or other launch vehicle is accomplished using a set of performance data, ground rules, and instructions for performing a capture analysis to establish the launch vehicle types and traffic rates per logistic operation necessary to deliver to orbit and support the satellite system. A capture analysis is the assignment of a payload to a launch vehicle capable of satisfying the mission requirement while at the same time minimizing system transportation costs.

b. Ground Rules and Assumptions for Capture Analysis

In the performance of capture analyses the following ground rules and assumptions should be noted and observed in lieu of other direction from NASA (e. g. , first flight dates are subject to change):

1. IOC of the Shuttle is assumed as late CY-1979.
2. Shuttle flight availability unlimited 1983 and after. For 1979-1983, capture on STS and expendable launch vehicles as alternatives.
3. Shuttle modified Centaur IOC same as Shuttle IOC; full capability Tug IOC CY 1985.
4. Turnaround time for both Shuttle and Tug is assumed to be two weeks.
5. Direct operating cost of the Shuttle \$9.8 M/flight; Tug \$0.89 M/flight, 1972 dollars.
6. KSC available as required 1980-1991.
7. WTR available in CY 1982.

8. STS used for multiple satellite deployment or replacement operations wherever possible. Assume that for payloads classed as "sharing" payloads, 82 percent of the time another payload will share the launch, either self-sharing or sharing with another payload.
9. Configure payloads to share launches by observing:
  - (a) Weight goal of 1/2 launch vehicle capability or less to allow for multiples
  - (b) Length goal of 1/2 orbiter payload bay [9.1 m (30 ft)] or approximately 3.7 m (12 ft) if Tug is utilized.
10. The maximum number of payloads simultaneously carried by a Shuttle is five.
11. Maximum number of payloads simultaneously carried by a Tug or injection stage is three.
12. On-orbit docking is available when necessary.
13. Shuttle payload bay dimensions are clear volume measurements, 4.5 m (15 ft) in diameter and 18.3 m (60 ft) long.
14. Expendable energy stages used when necessary with the Shuttle so as not to expend Tugs.
15. Payload recovery and reuse wherever possible is mode of operation for major payload cost savings.
16. The Shuttle maximum payload constraint is 29,500 kg (65,000 lb) for launches and includes the upper stage where applicable. The return payload limit is 14,502 kg (32,000 lb).
17. Projected launch vehicle reliability, 1980-1990:
  - (a) Expendable launch vehicle - average three percent losses
  - (b) Space Shuttle - no losses - average 0.5 percent abort-to-orbit
  - (c) Space Tug - average one percent losses - average one percent abort - average one percent mission completion in degraded transportation mode.

18. Payload infant mortality:

- (a) Expendable launch vehicle - average six percent losses
- (b) Space transportation - no losses - average six percent reflights.

19. Backup payloads, BRAVO application-type satellites:

- (a) Backup satellites are obtained from spare and redundant satellite requirements which are described in "satellite system approach" and refined in the risk analysis.

c. Launch Vehicle Data

(1) Shuttle

Information describing the Space Shuttle system as it relates to payloads is available in Ref. 1. This document provides potential users of the Space Shuttle system an official source of information on the planned accommodations for payloads. By using these data, payload planning and design studies can be conducted against a controlled set of accommodations. The baseline configuration of the Space Shuttle system described is consistent with current Space Shuttle program requirements. Data provided include performance data and information on payload interfaces, subsystems, environment, and support equipment.

(2) Upper Stages

Information describing the expendable upper stage (Centaur) is available in Ref. 2, 3, and 4. These documents provide the potential users with vehicle descriptions as well as performance data to use in capture analyses.

The reusable Tug configuration is presently under study. Tug performance and descriptive data of the MSFC 1972 Baseline Definition, which may be used for capture analyses are in Ref. 4 and 5. The data presented is in the form of payload capability in pounds as a function of

Delta velocity required above 296 km (160 nmi) injection altitude velocity provided by the Shuttle. Performance capability for Tug modes of operation for (1) deployment, (2) retrieval, (3) service (round trip), and (4) tandem Tug is provided.

(3) Launch Site

The launch site determination is accomplished from a review of the operational launch azimuths from the two planned launch sites and orbital inclinations obtainable from Ref. 1 or from the table below.

Space Shuttle Launch Azimuth Constraints

	Azimuth	Inclination	Inclination Range Accommodated*
<u>WTR Launches</u>			
Minimum	140°	56°	56° - 104°
Maximum	201°	104°	
<u>ETR Launches</u>			
Minimum	120°	39°	28.5° - 57°
Maximum	35°	56°	

\* Without dogleg maneuvers

(4) Ground Terminal (Link)

The communications and tracking subsystem provides the RF interface between the orbiter and EVA crewmen, other orbiting vehicles (including communication relay satellites), and ground facilities which include the space tracking and data network, air traffic control facilities, and orbiter landing site facilities. Specific functional descriptions of the communication links provided by the orbiter are in Ref. 1, Section 5.3. The orbiter-to-ground, orbiter-to-tracking and data relay satellite, orbiter-to-satellite control facility, and space-to-space links are described.

d. Capture Analysis Procedures

To perform a capture analysis it is necessary to input certain mission data, satellite data, including weight, size, mission requirements/ characteristics, number of satellites in orbit, schedule, and satellite life. Use Accommodation and Traffic Analysis forms (forms A&T-1, -2, -3, -4 in Volume IV, Part 3, Workbook) for the analysis. Follow the example in subsection e (page 4-76).

The following steps and procedures are provided for the collection of the data required and for performing a capture analysis:

1. Inputs, Program Definition
  - (a) Satellite destination - altitude - inclination
  - (b) Number of satellites
  - (c) Initial installation schedule
  - (d) Mission equipment model change schedule
  - (e) Satellite design inputs
    - (1) Weight
    - (2) Dimensions
    - (3) Mission duration - MMD
    - (4) Satellite logistics for reliability requirements (See paragraph b, page 4-71, items 17 and 18)
    - (5) Communications
    - (6) Review Table 3-1 of Ref. 1 for other weights and dimensions chargeable to the satellite.
2. Site selection determined from inclination shown in paragraph c, subparagraph (3), page 4-74 (or Ref. 1, Figure 3-1).
3. Calculate characteristic velocity ( $V_c$ ) for program destination [e.g., 296 km (160 nmi) circular = 7800 m/sec (25,600 ft/sec), synchronous equatorial = 12,100 m/sec (39,700 ft/sec)].
4. Determine  $\Delta V_c$ ;  $\Delta V_c = V_c - 7800$  m/sec (25,600 ft/sec).  
This is the velocity requirement above 296 km (160 nmi) to be used if an upper stage is required, e.g., synchronous equatorial 4300 m/sec (14,100 ft/sec).



5. Perform launch vehicle/payload accommodation analysis and estimate traffic:
- (a) Determine Shuttle payload capability for the satellite destination (Ref. 1, Figures 3-2 through 3-9). (These are low altitude destinations < 1300 km (700 nmi)).
  - (b) If Shuttle weight capability is equal to or greater than satellite then check dimensions (length and diameter).
  - (c) If Shuttle capability is not adequate, an upper stage is required.
  - (d) If first launch is scheduled prior to the full capability Tug availability (late 1983), then an expendable upper stage (interim upper stage), Centaur, will be used. Determine the Centaur capability for the  $\Delta V_c$  above from Ref. 3 or 4. If the weight capability is equal to or greater than the satellite, check for dimensions allowing for Centaur length of 9.3 m (30.5 ft). If the Centaur capability is not adequate, an expendable launch vehicle is required.
  - (e) If first launch is scheduled after full capability Tug is available (CY 1984), determine the Tug capability for modes of interest (deploy, retrieve, service, tandem) for  $\Delta V_c$  (Ref. 4).

After the accommodation analysis is complete and the modes of operation (deploy, retrieve, service) have been established for the program life, the Shuttle and upper stage traffic can be estimated. Reflights for reliability effects should be added to determine the total number for costing purposes. Reliability effects data are provided in the ground rules and assumptions section.

e. Satellite Transportation Accommodation and Traffic Analysis Example

The following example is provided for the purpose of defining the specific steps necessary to perform a satellite transportation accommodation and traffic analysis. Use forms A&T-1, -2, -3, -4 for the

analysis. The example satellite selected for accommodation by the Shuttle and upper stage is a synchronous earth observation satellite (SEO).

Step 1 - Inputs, Program Definition

- (a) Destination - 19,300 nmi circular altitude at  $0^{\circ}$  inclination.
- (b) Number of satellites on orbit - one.
- (c) Initial installation schedule - 1980.
- (d) Mission equipment and spacecraft model change schedule, assumed (see Table 4-6).
- (e) Satellite design inputs.
  - (1) Weight - CDR\* 475 kg (1048 lb), see SEO synthesis wet weights (Section 4 C).
  - (2) Dimensions - CDR 1.3 m (4.2 ft) length and 1.8 m (6.0 ft) diameter. See SEO synthesis lengths and diameters (Section 4 C).
  - (3) MMD - 2 years.
  - (4) Satellite and launch vehicle reliability parameters - Shuttle/Tug abort 2.5 percent, Centaur failures 3 percent, payload abort 6 percent. See items 17 and 18, Section D, 1, b.
  - (5) Other weights chargeable to satellite - 212 kg (467 lb) - adapter to interface with upper stage - see SEO synthesis weights (Section 4 C).

Step 2 - Site Selection - ETR for  $0^{\circ}$  inclination (See Ref. 1, Figure 3-1).

Step 3 - Characteristic Velocity - The velocity required for earth orbits can be obtained from Ref. 6. Enter Figure 3-1 at altitude of 19,300 nmi and using the curve for circular equatorial orbit from ETR one obtains a  $V_c$  of 39,700 ft/sec. For circular orbits other than equatorial the center curve should be used with Figures 4-1 and 4-2, which provide velocity penalties as a function of orbit inclination for ETR and WTR launch sites. For sun synchronous mission, Figure 3-6 should be used to obtain characteristic velocities.

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\* Current Design Reusable.

Table 4-6. Satellite Schedule and Traffic Form

SATELLITE NAME: Synchronous Earth Observation SatelliteCODE NO. SEOORBIT: Synchronous EquatorialLAUNCH SITE: ETR

Satellite Type Weight, Length/Diam.	Event	Schedule (Year)															
		80	81	82	83	84	85	86	87	88	89	90					
Current Design Reusable 475 kg (1,048 lb) 1.3/1.8 m (4.2/6.0 ft) 2 Year Cold Gas RCS	Up Flight	1		1		1		1		1		1					
	Down Flight					1		1		1							
	Revisit																
	M/E(1) Modification						1					1					
	S/C(2) Modification											1					
Current Design On-Orbit Maintainable 686 kg (1,512 lb) 1.7/2.4 m (5.5/7.9 ft) 2 Year Cold Gas RCS	Up Flight	1		1				1				1					
	Down Flight							1									
	Revisit					1				1							
	M/E(1) Modification						1					1					
	S/C(2) Modification											1					
Low-Cost Reusable 1,149 kg (2,534 lb) 2.0/2.8 m (6.4/9.1 ft) 2 Year Cold Gas RCS	Up Flight	1		1		1		1									
	Down Flight					1											
	Revisit						1		1	1	1	1					
	M/E(1) Modification						1					1					
	S/C(2) Modification											1					

(1) Mission Equipment

(2) Spacecraft

Step 4 - Determine the velocity required above 160 nmi.

$$\Delta V_c = V_c - 25,600 \text{ ft/sec}$$

$$= 39,700 - 25,600 = 14,100 \text{ ft/sec}$$

It should be noted here that when rendezvous and docking are required (e.g., satellite retrieval or service), an additional  $\Delta V_c$  allowance of 100 ft/sec should be included. If two satellites in the same orbit are to be retrieved or revisited, allow an additional 560 ft/sec; 1650 ft/sec for three satellites.

Step 5 - Perform Launch Vehicle/Payload Accommodation Analysis.

- (a) If the satellite IOC had been prior to the Shuttle IOC, e.g., a satellite launch from WTR prior to 1982, then an expendable launch vehicle would be used. Ref. 7 contains vehicle descriptions and data on the performance capability of current expendable launch vehicles.
- (b) Since the Shuttle capability is limited to altitudes below 700 nmi, an upper stage will be required to perform this mission (see Figure 3-2, Ref. 1).
- (c) Since the satellite IOC is 1980 and is prior to the Tug availability, an expendable upper stage accommodation is required (see Section C.1.b). The payload capability at  $\Delta V_c = 14,100 \text{ ft/sec}$  of the Centaur used as an upper stage with the Shuttle obtained from Figure 2-6 of Ref. 4 is about 5442 kg (12,000 lb). Table 9 of Ref. 2 shows the capability to be 5456 kg (12,031 lb). It should be noted that the Centaur is 9.3 m (30.5 ft) long and has a gross weight of 15,985 kg (35,246 lb).
- (d) In a similar fashion the Tug payload performance for  $\Delta V = 14,100 \text{ ft/sec}$  can be determined using Figures 2-1, 2-2, 2-3, and 2-5 of Ref. 4. Note that the Tug performance is constrained to 29,500 kg (65,000 lb) Shuttle capability.

Deployment	3,990 kg	( 8,800 lb)
Retrieval	2,270 kg	( 5,000 lb)
Deploy and Retrieve	1,380 kg	( 3,050 lb)
Tug Expended	8,620 kg	(19,000 lb)

The Tug length is 10.7 m (35 ft).

At this point the payload weights and dimensions have been generated by the satellite synthesis program and the launch vehicle performance for the satellite destination has been determined. A satellite weight and dimension comparison can be made with the launch vehicle capability to perform the accommodation analysis.

#### Satellite Characteristics

	CDR (Ground Refurbished)	CDOM (On-Orbit Maintenance)	LCR (On-Orbit Maintenance)
Launch Weight on Centaur, kg (lb) <sup>(1)</sup>	687 (1,515)	745 (1,642)	1,218 (2,685)
Launch Weight on Tug, kg (lb)	475 (1,048)	686 (1,512)	1,149 (2,534)
Length on Centaur, m (ft) <sup>(1)</sup>	2.4 (8.0)	2.5 (8.3)	2.6 (8.6)
Length on Tug, m (ft)	1.3 (4.2)	1.7 (5.5)	2.0 (6.4)
Diameter, m (ft)	1.8 (6.0)	2.4 (7.9)	2.8 (9.1)

(1) Including adapter

(a) STS/Centaur

All satellite types can be deployed by this launch vehicle. Note that both weight and length will allow for multiple payload deployment. If the satellite plus adapter length exceeds 9.0 m (29.5 ft) or weighs more than 5,442 kg (12,000 lb), an expendable launch vehicle would be required.

(b) STS/Tug (Reuse)

(1) Deployment Only

All satellite types can be deployed by this launch vehicle. Note that both weight and length will allow for multiple payloads. If the satellite weight exceeds

3,990 kg (8,800 lb), but is less than 5,442 kg (12,000 lb) or if the length exceeds 7.6 m (25 ft), it may be deployed on a Centaur upper stage.

(2) Retrieval Only

All satellite types can be retrieved by this launch vehicle. Note that both weight and length will allow for multiple retrieval. In the event that the satellite can be deployed by the Tug, but not retrieved, i.e., weight in excess of 2,270 kg (5,000 lb) but less than 3,990 kg (8,800 lb), on-orbit maintenance should be considered. The launch vehicle traffic is then based upon a service trip to the satellite to update or refurbish where indicated on the traffic model.

(3) Deploy and Retrieve

All satellite types can be deployed and retrieved by this launch vehicle. Multiple CDR payloads can be replaced by a single Tug trip; however, the LCR uses the Tug round-trip capability. If the satellite weight exceeds 1,380 kg (3,050 lb), deploy and retrieve may be accomplished by separate Tug trips. Consideration of multiple payloads will reduce the program portion of the additional launches.

(c) STS/Tug (Expendable)

All satellite types can be deployed by this launch vehicle. Both weight and length will allow for multiple payload deployment. A Centaur should be considered rather than expending a Tug.

Step 6 - Traffic Analysis

The next step in a capture analysis is to estimate the launch vehicle traffic. A review of the satellite traffic in Table 4-6 shows the first launch in 1980 with subsequent launches every other year. Since the launches in 1980 and 1982 are prior to Tug IOC, the Shuttle Centaur launch vehicle will be used and no retrieval is possible. A replacement mode of operation should be used where possible. A revisit mode of operation is illustrated using the low-cost reusable configuration.

The launch vehicle traffic for the CDR and CDOM configurations is the following:

	<u>80</u>	<u>81</u>	<u>82</u>	<u>83</u>	<u>84</u>	<u>85</u>	<u>86</u>	<u>87</u>	<u>88</u>	<u>89</u>	<u>90</u>	<u>Total</u>
Shuttle	1		1		1		1		1		1	6
Centaur	1		1									2
Tug					1		1		1		1	4

The launch vehicle traffic for the LCR configuration operation is slightly different due to the revisits.

	<u>80</u>	<u>81</u>	<u>82</u>	<u>83</u>	<u>84</u>	<u>85</u>	<u>86</u>	<u>87</u>	<u>88</u>	<u>89</u>	<u>90</u>	<u>Total</u>
Shuttle	1		1		1	1	1	1	1	1	1	9
Centaur	1		1									2
Tug					1	1	1	1	1	1	1	7

Reflights due to reliability effects must be added to the launch vehicle traffic. The ground rules are listed on pages 4-71 through 4-73 of this report.

- (a) Expendable launch vehicle (Centaur) add 3 percent
- (b) Tug add 0.5 percent
- (c) Shuttle add 0.5 percent
- (d) Payload infant mortality add 6 percent

Therefore, increase the Shuttle/Centaur flights by 9.5 percent, the Shuttle/Tug payload deployment flights by 8.5 percent, and the Shuttle/Tug retrieval flights by 2.5 percent. As was noted earlier, both weight and length will allow for multiple deployment and/or retrieval. Since the traffic to synchronous equatorial orbit is high, the opportunity for multiple payloads sharing launch charges is great; therefore, the launch vehicle charge to the program would be reduced when considering a complete mission model.

To estimate the percent of the launch vehicle charges to assess a program, an overall synchronous equatorial load factor of 80 percent of the upper stage capability may be assumed. For example, the Tug round trip capability is 1,380 kg (3,050 lb) and then 80 percent is 1,104 kg (2,440 lb). If the satellite of interest weighs 687 kg (1,515 lb), then  $687 \text{ kg (1,515 lb)} \div 1,104 \text{ kg (2,440 lb)}$  or 62 percent of the launch vehicle is charged to the program.

f. Background

Capture analyses using essentially the methodology described above have been performed in Study A, Integrated Operations/Payloads/Fleet Analysis (FY 1971); Study 2.1, Space Shuttle Mission and Payload Capture Analysis (FY 1972); and in Study 2.4, Space Shuttle/Payload Interface Analysis (FY 1973). Many of the ground rules and assumptions have evolved from early capture analyses for use in future captures. The launch vehicle fleets varied from expendable, as used in today's space program, to a fully reusable Space Shuttle system. Both ETR and WTR launch sites were involved.

2. SATELLITE GROUND TERMINAL DEFINITION AND COST ESTIMATE

a. Earth Stations Supporting Non-Communications Satellites

Earth stations are required by satellite systems other than communication satellite systems for receiving and relaying data from the satellite and for telemetry, tracking, and command of the satellite and its mission equipment.

The most extensive data and experience on supporting earth stations and communication nets for non-communications satellites have been accumulated on NASA's Space Tracking and Data Network (STDN). Data on STDN system capabilities and equipment for the late 1970s are provided in Vol. IV, Part 4, Section 6 in order that the requirements for data communications, telemetry, tracking, and command support for a prospective satellite mission may be compared with STDN capabilities.

Costs for STDN support and cost data for particular stations (of interest if additional mission-dedicated stations were to be required) have not been made available by NASA. These data have been the subject of extensive studies for purposes of establishing a basis for equitable charges to users of the system, particularly non-NASA users; however, the studies had not been concluded and their release authorized to allow



the data to be included herein. For information on the availability of such data, refer to William Pfeiffer, Code 361, Goddard Space Flight Center, Greenbelt, Maryland.

b. Telecommunication Satellite System G/T Selection

The procedures herein apply specifically to the most common configuration of communication satellite systems, which employ satellites in geosynchronous orbit and earth stations which transmit and receive through tracking antennas capable of pointing at one or another of the satellites in the system (at least two satellites in orbit are usually required for redundancy and reliability of operations).

The system design of such a satellite system is influenced primarily by the numbers and location of earth stations and satellites and by traffic requirements, which determine the communication capacities of earth stations and satellites. In addition, design is affected by the transmission frequencies of the system which are limited by regulations on the use of the electromagnetic frequency spectrum.

In order to design earth stations and satellites to meet these requirements at the least cost, the individual satellite-earth station links must be analyzed to determine the power, antenna gains, and receiving electronics of satellites and earth stations which will result in minimum cost for the system as a whole. The procedure for accomplishing this requires iterative calculations, a few of which will be adequate in most instances to establish the variation in total system cost, and the minimum cost, with variation of the interrelated satellite and earth station parameters. The calculations determine the power requirements and antenna sizes of satellites for communication with an earth station with a selected receiving system "Figure of Merit",  $G/T^{(1)}$ . Costs

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(1)  $G/T$  is the ratio of antenna gain to the receiving system noise temperature equivalent in degrees Kelvin, which includes noise from the antenna system and receiving preamplifier. The ratio is expressed in decibels (10 times the logarithm of the ratio) per degree Kelvin.

can be estimated for satellites and earth stations which meet these requirements, and total system costs can then be determined, taking account of the quantities of each. By selecting various values of earth station G/T and calculating the corresponding satellite, earth station, and system costs, the minimum system cost may be determined.

Reference should be made to other similar BRAVO analyses to determine whether the G/T selection can be made from existing data without further analysis.

In order to estimate system parameters and costs, the following system requirements must be established. In cases where they have not been determined, approximate values must be established as a starting point.

- Number and location of earth stations
- Traffic between each earth station and all others, via satellite, in terms of numbers of voice channels or numbers of 4000 bit-per-second data channels. (1)

Other inputs, required for sizing the satellite mission equipment are specified in Section 4. B. 1.

Calculation of system costs should proceed as follows:

- (1) Obtain the G/T value(s) to start this ground link station analysis from Section 4. A. 7. d. Obtain the link frequency from the analysis in Section 4. B. 1.
- (2) Estimate cost per earth station (see section c. (1). (4), page 4-89) using the initially assumed value of G/T.
- (3) Estimate satellite weights based on the link parameters determined in Step (1) above.

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(1) A channel carries communications one way; two channels are required for a two-way, simultaneous telephone conversation.

- (4) Estimate cost per satellite in orbit.
- (5) Estimate system cost (the total of costs for all satellites and all earth stations).
- (6) Compare system costs for alternative initial values for G/T and select the lowest cost approach.
- (7) If necessary, repeat the above steps assuming different initial values for G/T and plot the system cost for each value of G/T to determine the value of G/T and the corresponding parameters for earth stations and satellites that result in minimum system cost.

The procedure above determines the configuration of earth stations and satellites with the minimum investment cost for the total system. Operating costs are excluded, for simplicity in calculations, inasmuch as they are strongly related to investment costs and their exclusion does not significantly alter the choice of the optimum configuration. For purposes of comparing the optimized system with other systems, the operating costs should be calculated and included.

Table 4-7, "Worksheet, Satellite Communication System Trade-off Analysis," provides for the orderly arrangement of inputs and calculates values for the procedure, above. If the calculated system investment costs for three different values of earth station G/T are plotted against G/T, the curve drawn through the three points will usually indicate the value of G/T which will result in minimum system investment cost.

Table 4-7. Worksheet, Satellite Communication System Tradeoff Analysis

System Designation \_\_\_\_\_

No. of Earth Stations \_\_\_\_\_

Location (Area) of Earth Stations \_\_\_\_\_

No. of Satellites \_\_\_\_\_

For other inputs, see Section 4. B. 1.

Earth Station G/T, dB/°K						
Earth Station Unit Investment Cost <sup>(1)</sup>						
Satellite Weight <sup>(2)</sup>						
Satellite Unit Investment Cost in Orbit <sup>(3)</sup>						
System Investment Cost <sup>(4)</sup>						
Earth Stations						
Satellites						
Total						

(1) Calculations, Section 4. D. 2. c (page 4-88)

(2) Calculations, Section 4. D. 2. c (page 4-88)

(3) Calculations, Section 4. D. 2. c (page 4-88)

(4) Unit costs of earth stations and satellites times quantities of each.

c. Telecommunications Satellite Earth Station Definition and Cost Estimate

A satellite earth station provides the communications connection between satellites and points on the earth's surface or in the atmosphere. The discussion herein is limited to permanent installations on land employing steerable parabolic antennas.

The functions performed by earth stations are: (1) receive communications from terrestrial points (originating either at the station or at remote points in the terrestrial communications network), multiplex the signals (arrange in frequency and time sequence); (2) modulate the transmitter, the output of which is beamed at the satellite by the antenna; and (3) receive communications from the satellite through the antenna, amplify and demultiplex the signals, and connect them into the terrestrial communications network.

The earth station facilities include, typically, a building for housing the electronic equipment, a standby power source, connections to commercial power, one or more antenna systems (including the antenna reflectors and feeds, mounting structure, and servo systems for antenna pointing), and other facilities such as fencing, roadways, and parking provisions.

Earth station antennas are designed to produce very narrow beams, on the order of one degree beam width, in order to achieve high gain and reduce power requirements and to avoid interference with other communications facilities using the same frequency. Thus, one antenna beam is required for each satellite that must be communicated with simultaneously. In practice, one antenna system is required per beam. Multiple feeds and beams using a single antenna reflector, though possible, require larger and more costly reflectors to offset losses from mutual blockage by the feeds, and the loss of reflector efficiency when a beam deviates from the reflector axis by more than a few degrees severely restricts operating flexibility.

(1) Costs

Certain inputs necessary to calculate earth station costs must be established in the course of defining the satellite system, of which earth stations are one part. These inputs are:

- (1) Frequency of transmission and reception, expressed usually in gigahertz, or  $10^9$  Hertz. If these frequencies are not defined, they may be selected using the procedures in Section 4. B. 1.
- (2) Capacity in terms of number of communication channels, either telephone voice channels or 4000 bit-per-second data channels (a channel carries one-way communication; two channels are required for a two-way voice circuit).
- (3) Number of antenna systems,  $N_a$ . One antenna system and receiving preamplifier are required for each satellite with which the earth station must communicate simultaneously.
- (4) Receiving system figure of merit,  $G/T$ , expressed in  $\text{dB}/^\circ\text{K}$ . This is the ratio of the antenna gain ( $G$ ) to the receiving system noise temperature ( $T$ ) in degrees Kelvin, contributed by the antenna and receiving preamplifier, expressed in decibels (10 times the logarithm of the ratio). If this figure has not been previously established by the system design, then a value must be assumed. For earth stations with a capacity of more than 200 channels, assume  $G/T = 40 \text{ dB}/^\circ\text{K}$ ; for 50 to 200 channels, assume  $G/T = 32 \text{ dB}/^\circ\text{K}$ ; and for fewer than 50 channels,  $G/T = 25 \text{ dB}/^\circ\text{K}$ .

(a) Investment Costs

Investment costs are calculated using the worksheet, Table 4-8, "Satellite Earth Station Costs," which provides a format for calculation of the values in the following expression:

$$\text{Cost} = \left\{ \left[ [(A+R)N_a + (\text{PMT})N_a^{0.5}] (\text{MIT}) + (\text{SB}) \right] (\text{Msc1}) + (\text{MMT}) \right\} (\text{F}_c)(1.08)^{-n}$$

where costs are in 1973 dollars, and,

- A = Antenna system cost (Figure 4-21)  
R = Receiving preamplifier cost  
 $N_a$  = Number of antenna systems

PMT = Power, monitoring, and test equipment (Figure 4-22)  
 MIT = Management, integration, and test = 1.33 factor  
 SB = Site and building costs (Figure 4-23)  
 Mscl. = Miscellaneous costs = 1.33 factor  
 MMT = Multiplexing modulation, and transmitter costs (Figure 4-24)  
 $F_c$  = Construction area cost factor (Table 4-9)  
 n = Year construction completed minus 1973

(b) Annual Operations Costs

Annual operations costs are calculated at 12.6 percent of the original investment cost. These costs include the annual direct expenditures for maintenance and operating personnel; for direct maintenance and operating spares, materials, and services; and for allocated system overhead costs. They do not include depreciation and return on investment.

(2) Calculation/Instructions

Calculations on the worksheet, Table 4-8, proceed as follows:

Line 1: Calculate antenna gain by adding  $G/T$  (dB/°K) and the receiving system noise temperature,  $T$  (dB°K). Selection of  $T$  involves a tradeoff between preamplifier costs,  $R$ , and antenna cost,  $A$ . For a given  $G/T$ , increasing  $T$  (using a lower cost uncooled preamplifier) must be offset by increasing  $G$  (larger and more costly antenna) to maintain  $G/T$  constant. For the calculations herein it is sufficient to select one of two receiving preamplifier costs,  $R$ , and the corresponding receiving system equivalent noise temperatures,  $T$ :

	<u>"R"</u>	<u>"T"</u>
Uncooled Preamplifier	\$15,000	22.5 dB°K
Cooled Preamplifier	\$70,000	17.5 dB°K

For values of  $G/T > 35$  dB/°K, assume  $T = 17.5$  dB°K. For values of  $G/T < 25$  dB/°K, assume  $T = 22.5$  dB°K. For values of  $G/T$  between 25 and 35 dB/°K, select  $T$  to obtain the lower cost of  $(A+R)$  using Figure 4-21. Enter the figure at the appropriate frequency. Add  $G/T$  and  $T$

to obtain the antenna gain, G, and read the cost, A. Add the cost, A, to the cost, R, corresponding to the value of T selected. Use the value of T which results in the lesser cost of (A+R).

Line 2: Read the antenna system cost from Figure 4-21 at the appropriate frequency and value of antenna gain, G.

Line 3: Use the value of R corresponding to the value of T selected in line 1.

Calculations on lines 4 through 18 are self-explanatory. The calculations are the same as for the expression, above, except for the change of form in lines 9 and 11, where, for convenience in calculating, (MIT) and (Msc1) are calculated using a percentage of preceding costs rather than a factor being used to calculate totals which include these elements.

Investment and annual operation costs for earth stations should be summarized by year, the form required for input to the cost-effectiveness analysis is given in Table 4-10. In cases where a system involves only a few earth stations, they may be listed separately with the kind of cost, investment or operating, indicated in the second column. Investment costs should be allocated two-thirds to the year preceding the year of first operation and one-third to the second year preceding operation. Annual operating costs should start with the first year of operation and continue for the life of the station. For cost estimating purposes, a station is assumed to have a 12-year life, at the end of which a new station is required to replace the "obsolete" station.

Several stations may be grouped, for convenience in calculation, where their first operation year is the same.



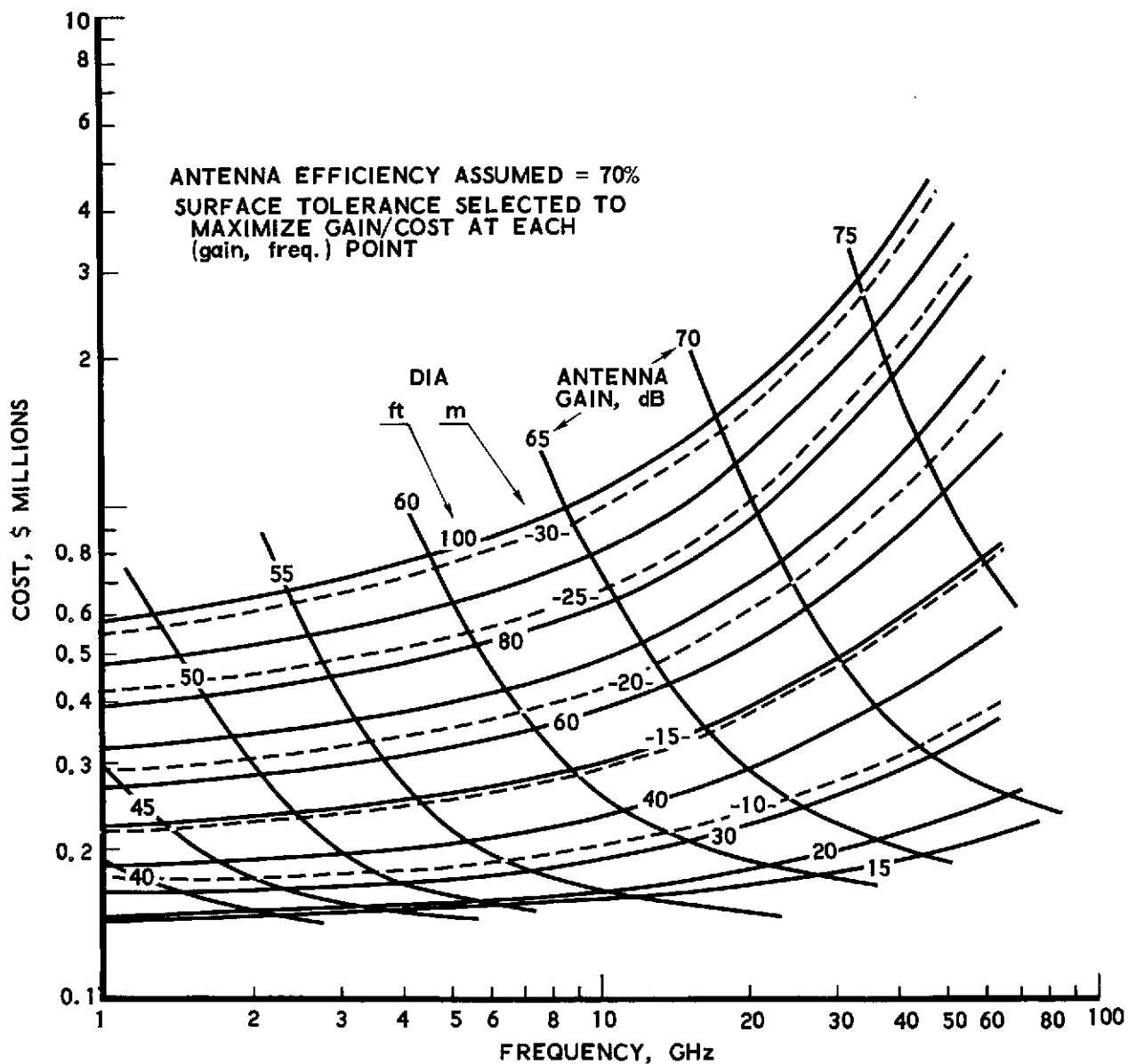


Figure 4-21. Cost of Minimum-Cost Exposed Antenna Systems for Fixed Frequency and Gain vs Frequency and Gain

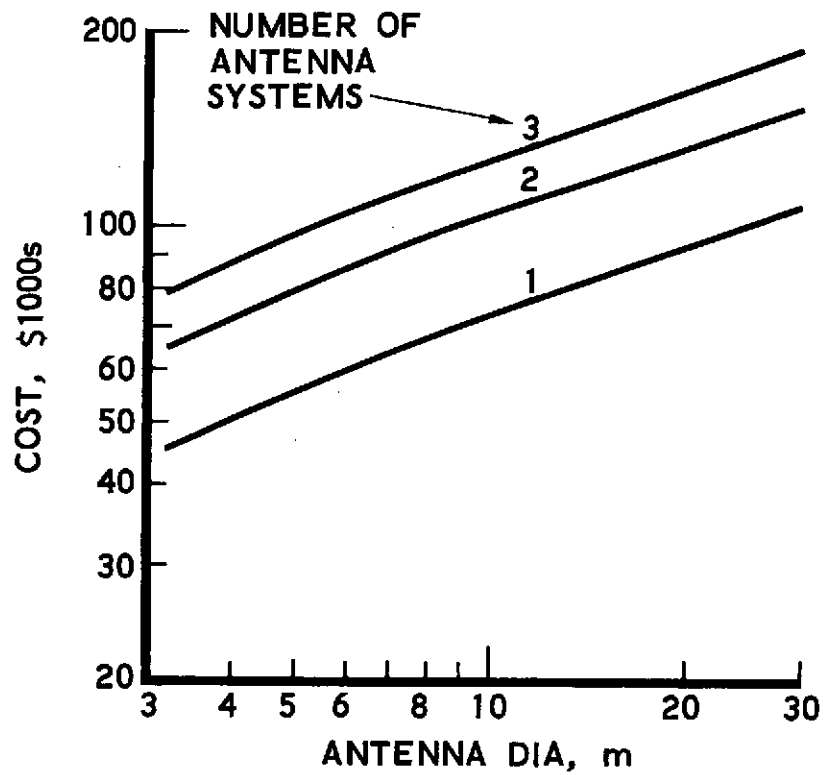


Figure 4-22. Investment Cost, Power, Monitoring, and Test Equipment for Satellite Earth Station

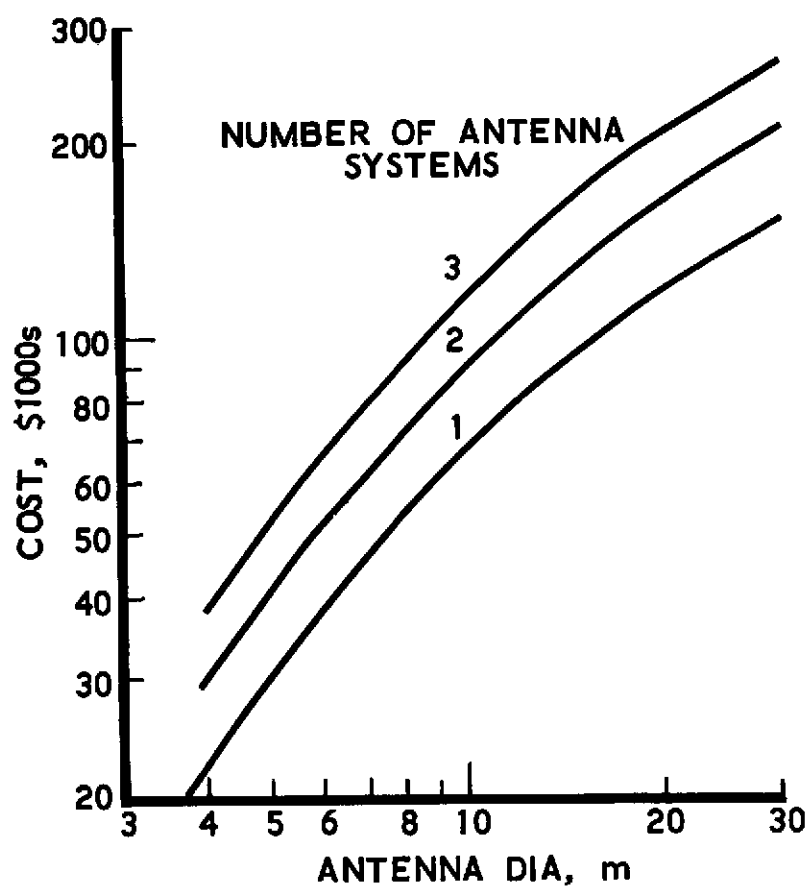


Figure 4-23. Site and Building Investment Cost for Satellite Earth Station

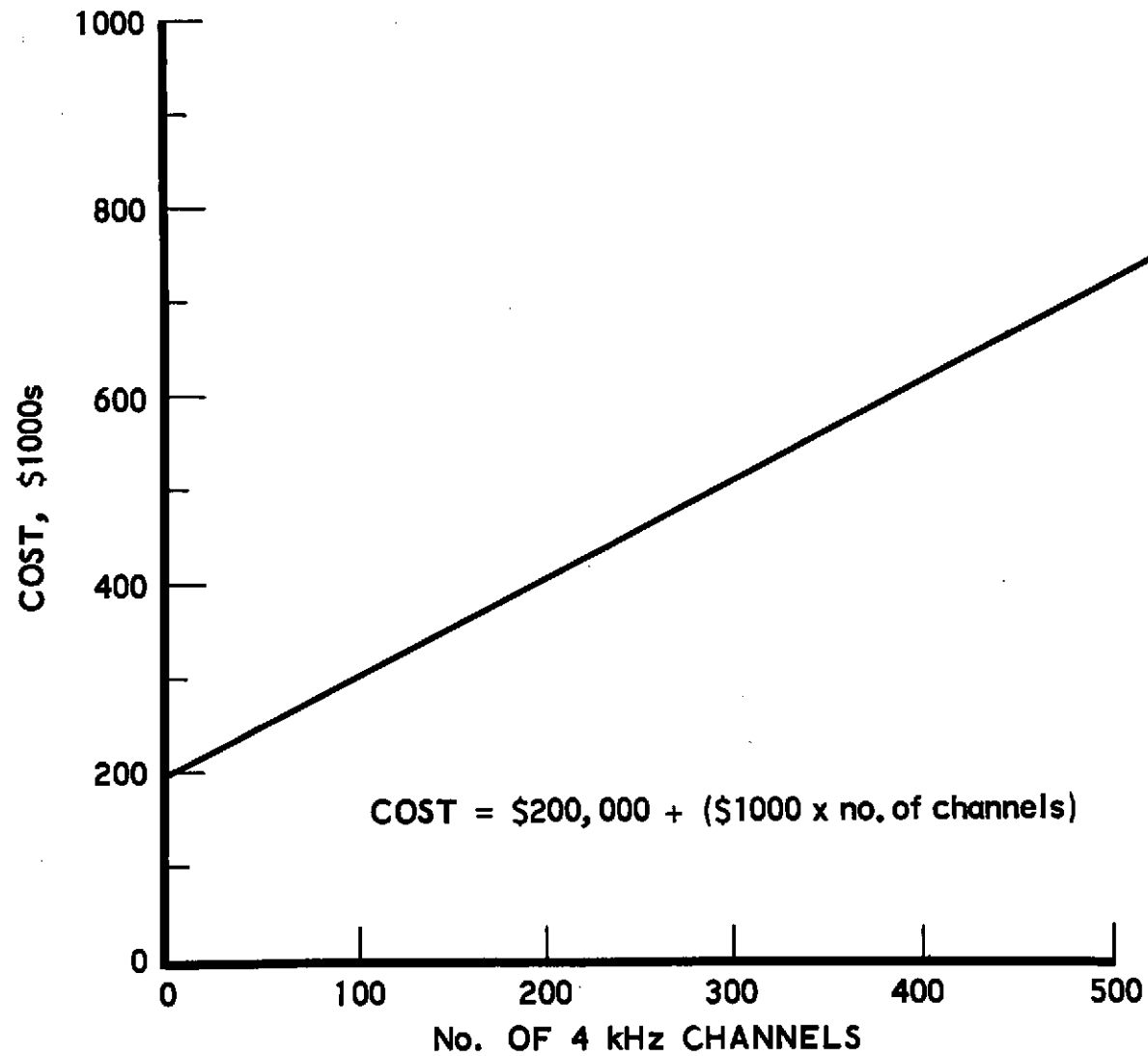


Figure 4-24. Multiplexing, Modulation, and Transmitter Investment Cost

Table 4-8. Worksheet - Satellite Earth Station Costs

INPUTS:      Frequency Downlink \_\_\_\_\_ GHz  
               Number of Channels \_\_\_\_\_  
               Receiving System Figure of Merit, G/T \_\_\_\_\_ dB/°K  
               Number of Antenna Systems,  $N_a$  \_\_\_\_\_  
               Year Construction Completed \_\_\_\_\_

CALCULATIONS:

1.      Antenna Gain,  $G = G/T + T = ( \quad ) \text{dB}/^\circ\text{K} + ( \quad ) \text{dB}/^\circ\text{K} = ( \quad ) \text{dB}$

INVESTMENT COST

- |     |  |  |
|-----|--|--|
| 2.  | Antenna System Cost, A, From Figure 4-21             |  |
| 3.  | Receiving Preamplifier Cost (R)                      |  |
| 4.  | Sum, Lines 2 + 3                                     |  |
| 5.  | No. Antenna System ( $N_a$ ) times Line 4            |  |
| 6.  | Power, Monitor, and Test (PMT) from Figure 4-22      |  |
| 7.  | $(N_a^{0.5})$ times Line 6                           |  |
| 8.  | Sum, Lines 5 + 7                                     |  |
| 9.  | Mgmt., Integr., and Test, [(MIT)-1] = Line 8 X 33%   |  |
| 10. | Site and Building Costs (SB) from Figure 4-23        |  |
| 11. | Sum, Lines 8 + 9 + 10                                |  |
| 12. | Miscellaneous Costs, [(Msc1)-1] = Line 11 X 33%      |  |
| 13. | Multiplex Modulation & Trans. (MMT) from Figure 4-24 |  |
| 14. | Sum, Lines 11 + 12 + 13                              |  |
| 15. | Const. Area Cost Factor ( $F_c$ ) from Table 4-9     |  |
| 16. | Yr. Const. Completed Minus 1973 (n)                  |  |
| 17. | Calculate: $1 / (1.08)^n$                            |  |
| 18. | Total Investment Cost, Lines 14 X 15 X 17            |  |

ANNUAL OPERATING COST

- |     |                                     |  |
|-----|-------------------------------------|--|
| 19. | Cost per Year = (0.126) X (Line 18) |  |
|-----|-------------------------------------|--|

Table 4-9. Construction Cost Factors

Area	General Cost Factor <sup>(1)</sup>	Area	General Cost Factor <sup>(1)</sup>
U. S. Contiguous	1.0	Europe	
Offshore Islands	1.3 - 1.5	Nordic, Germany	1.2 - 1.4
Canada		UK, France	1.0 - 1.1
Southern, Populated	1.0	Mediterranean	1.0 - 1.1
Southern, Interior	1.6	North Africa	1.0 - 1.3
Northern, Interior	3.0	Near East	
Alaska		Turkey	1.1
Anchorage, Fairbanks, Whittier, Juneau, Kenai Peninsula	1.8 - 2.0	Saudi Arabia	1.5
Nome	2.3	Afghanistan	1.5
Ft. Yukon	2.6	Iran	0.9
Aleutian Chain	3.0	Iraq	1.3
North Coast	3.5	Pakistan, W.	1.2
Inland, Remote	4.0	South Asia	
Canal Zone	1.3	India	0.9
Hawaii		Ceylon	1.1
Oahu	1.3 - 1.4	Burma	1.4
Other Islands	1.6	Laos	0.8
		Vietnam	2.3

(1) Most of these factors apply to areas which are relatively close to local population and transportation. Where locations are remote from population and transportation or where climate is severe, these factors should be adjusted upward using the factors provided as a guide.

Table 4-9. Construction Cost Factors (Cont'd)

Area	General Cost Factor <sup>(1)</sup>	Area	General Cost Factor <sup>(1)</sup>
Pacific Islands	2.0 - 2.5	Australia	
Formosa	0.6	South Coast	1.1
Japan	0.8	North Coast	2.3
Okinawa	1.0	New Zealand	0.8
Caribbean	1.3		
Central America	1.0 - 1.2		
South America			
North Coast	1.3		
Central and Southern	1.5 - 1.9		
Greenland			
Thule	3.5		
Ice Cap	4.0		
Iceland	3.0		

SOURCE: Defense Communications Agency Cost Manual, DCA Circular 600-60-1,  
17 November 1970

Table 4-10. Worksheet, Satellite Earth Station Cost Summary

Earth Station Designation	Years →												
	Investment Or Operations												



### 3. REFERENCES

#### Space Shuttle

1. Space Shuttle System Payload Accommodations, Johnson Spacecraft Center, JSC 07700, Vol. XIV (13 April 1973).

#### Centaur

2. Centaur/Shuttle Integration Study, Convair Aerospace Division of General Dynamics, GDCA-BNE 73-006-5 (15 June 1973).
3. Compatibility of a Cryogenic Upper Stage with the Space Shuttle, Convair Aerospace Division of General Dynamics, GDCA-BNE 71-020-7 (April 1972).

#### Tug

4. Space Shuttle/Payload Interface Analysis Final Report Volume II, Space Shuttle Traffic Analysis, The Aerospace Corporation, ATR-74(7334)-1, Vol. II (August 1973).
5. Baseline Tug Definition Document, NASA Marshall Space Flight Center (15 March 1972).

#### General

6. Launch Vehicle Estimating Factors for Advance Mission Planning, NASA-NHB 7100.5A, 1972 Edition.
7. Integrated Operations/Payloads/Fleet Analysis Mid-Term Report, Volume IV, Launch Systems, The Aerospace Corporation, ATR-71(7231)-9, Vol. IV (19 March 1971).

## E. SPACE SYSTEM COST ESTIMATING

### 1. BACKGROUND

From past studies, a comprehensive payload program cost model has evolved that is primarily used for analyzing total space plans composed of numerous individual payload (satellite) programs. This basic cost model has been simplified and transferred to a remote console computer system so that single payload programs can be estimated quickly and efficiently for BRAVO analyses. The purpose of this section is (1) to provide a description of the basic cost model, (2) to define the inputs it requires, and (3) to discuss the output of the cost model.

### 2. PAYLOAD PROGRAM COST MODEL

The computerized model is composed of two major sections; the payload cost model estimates costs and the launch cost model deals with launch vehicle chargeable costs. In the case of expendable vehicles, expendable hardware costs and launch site operations and support are included. For Shuttle and Tug launches, NASA cost per flight includes such items as expendable drop tank hardware, prorata solid motor hardware, propellants (solid and liquid), recovery, refurbishment, spares, and all direct costs at the launch site for facility maintenance, launch operations, and launch support.

Satellite cost is defined as all costs required to design, develop, manufacture, and test satellites and support them during launch and orbital operation. Typically, a satellite program is divided into RDT&E (nonrecurring), investment (recurring), and operations (recurring) cost categories. The model spreads the RDT&E costs over three years<sup>(1)</sup>. RDT&E covers design, development and test; investment includes procurement of satellite hardware; operations covers support during and after launch. In cases where reuse through ground refurbishment is considered, the operations cost category also includes satellite repair and refurbishment

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(1) User may vary spread from two to five years.

The payload cost model calculates basic RDT&E and unit costs from payload data input to the program. Cost-estimating relationships (CERs) stored in the program are automatically applied to these inputs. Launch vehicle cost per flight is also an input. Based on payload and launch vehicle schedules, total direct costs are calculated and fiscal funding requirements are determined by the model, all of which are printed in suitable formats.

### 3. COST MODEL INPUTS

The physical and performance data and the descriptive and schedule information required for operating the cost model are set forth in worksheet form in Tables 4-11 through 4-13. (Table 4-13 contains input data that are nominal values set in the computer program; however, they can be overridden as occasion demands.) Descriptions of all these inputs and the necessary assumptions that relate to their use are presented in this section.


#### a. Title and Satellite Type

For identification purposes, a title is required; the input format, i.e., NAME ← '.....', is shown in Table 4-11. The program demands that the type of satellite be noted, i.e., current design reusable (CDR) or low-cost reusable (LCR); TYPE ← 2 (or 3, respectively). Current design reusable means that current technology and design procedures are used but that they are modified to allow for reuse through ground refurbishment. Low-cost designs are based on data from LMSC<sup>(1)</sup> and assume that payload weight and volume constraints may be relaxed so that (1) lower cost components and materials can be used, (2) less testing is needed for design verification and qualification, and (3) fewer parts are needed for tests. These low-cost designs are also compatible with ground-based refurbishment.

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(1) Design Guide for Low-Cost Standardized Payloads, LMSC-D154696, Volumes I, II, NASA Contract NAS W-2312 (30 April 1972)

Table 4-11. BRAVO Worksheet - Satellite Cost Estimate  
Basic Input Information

Input Variable	Input Value(1)	Input Description	Remarks
NAME ←	' _____ '	Title	Name for Identification
TYPE ←	(2, 3)	Satellite Type	Current design for reuse, low-cost design
WS ←		Structure Weight	Reference expendable weights by subsystem. If satellite is current design reusable (CDR), subsystem weights for reusable design must also be entered (1b).  
WE ← WER ←(2)		Electrical Power Weight	
WC ←(2) WCR ←		Communications Weight	
WA ←(2) WAR ←		Stability & Control Dry Weight	
WAP ←(2) WAPR ←		Stability & Control Propellant Weight	
WP ←		Propulsion Inerts Dry Weight	
WPP ←		Propulsion Propellants Weight	
WM ←(2) WMR ←		Mission Equipment Weight	
M2 ←	(1 to 4)	Mission Equipment Type	
E1 ←		Init. Elec. Power	
			Watts

(1) For definition of numerical code see section 3 a-j.

(2) Input variable for CDR-type satellite.

Table 4-11. BRAVO Worksheet - Satellite Cost Estimate  
Basic Input Information (Cont'd)

Input Variable	Input Value <sup>(1)</sup>	Input Description	Remarks
P2 ←	(1 or 4)	Propulsion Type	Solid or liquid, if system needed
P1 ←		Propulsion Total Impulse lb/sec	If subsystem needed
C1 ←	(1, 2)	Orbit Altitude	Low/synchronous or planetary
LES ←		No. of Satellites In System	No. of satellites required in orbit for system to operate
LCT ←	(1 to 3)	Design Type (If Low Cost)	If low-cost design is to be considered, the type will be one of three; communications, navigation, or observation
YR ←		Constant Year Dollars	e.g., 1973
LVTYPE ←	(1 to 3)	Launch Vehicle Type	Shuttle, Shuttle and Tug, or other

(1) For definition of numerical code see section 3 a-j.

Table 4-12. BRAVO Worksheet - Satellite Cost Estimate  
Schedule Input Information

Item \ FY	Input Variable																			
RDT&E <sup>(1)</sup> (New or Modified)																				
Spacecraft	SSRS←																			
Mission Equipment	SSRME←																			
SATELLITE LAUNCHES																				
New	SSNEW←																			
Refurb.	SSREF←																			
STS LAUNCHES																				
Shuttle	LVS1←																			
Shuttle + Tug	LVS2←																			
Other <sup>(2)</sup>	LVS3←																			

(1) Schedules for RDT&E should normally coincide with first year of launch of new or redesigned satellite.

(2) Could be an expendable stage or Shuttle and expendable upper stage combination.

Table 4-13. BRAVO Worksheet - Satellite Cost Estimates  
Additional Inputs\*

Nominal Input Value	Input Description	Remarks
Sl ← 2	Structure Type	Nominally Exostructure
Al ← 3	Stability Type	Nominally 3-Axis
FLYP ← 79	First Year of Launch Schedule	Nominally 1979
YRD ← 3	Span of RDT&E	3 (Versus 4 Years or More)
RR ← .39	Refurbish Rate (For Ground Refurbishment)	CDR Nominal is 39 Percent (LCR is 30 Percent)
ALV1 ← (see remarks)	Launch Vehicle Cost	Nominally, if LVTYPE = 1, ALV1 = 10.26 LVTYPE = 2, ALV1 = 11.19

\* These inputs are automatically set at nominal values, which are used unless overridden by a new input.

b. Subsystem Weights

Reference (current design expendable satellite) weights are an input to the cost-estimating relationships (CERs) which are based on current expendable satellites. Factors are applied to the reference estimates to give effect to low-cost reusable design cost estimates. For current design reusable satellites, cost factors are based on differences in weight from reference subsystems and thus require reusable satellite subsystem weight data. The computer inputs are set forth in Table 4-11 and are split into two groups; one represents the reference weights and the second represents the current design reusable weights. Only one input is required for structure, i.e., the final structure weight. Similarly, the propulsion weights, if applicable, need single values only.

c. Mission Equipment Type

Four types of mission equipment are identified in the cost model: (1) communications, (2) navigation, (3) earth resources, and (4) meteorology. For a particular estimate the most appropriate category must be selected from the list. Thus, the input would be  $M2 \leftarrow 1$  for communications mission equipment.

d. Initial Electrical Power

Input requires initial output of the electrical subsystem to be given in watts, e.g.,  $E1 \leftarrow 150$ .

e. Propulsion Type and Total Impulse

An integral propulsion system may occasionally be required by an STS satellite. (A propulsion system requirement should not be confused with the reaction control propulsion, which is included in the stability and control subsystem.) The type of propulsion system refers



to the propellant used, either solid or liquid; the input would be either  $P2 \leftarrow 1$  (or 4). Total impulse in lb/sec is also a required input when a propulsion subsystem is needed, and an example input would be  $P1 \leftarrow 20000$ .

f. Orbit Altitude

The orbital altitude at which the satellite operates is a required input; one of two categories is entered, i. e.,  $C1 \leftarrow 1$  (for low or synchronous) or  $C1 \leftarrow 2$  (for escape).

g. Number of Satellites in System

Many programs require more than one satellite to be in orbit during operations. The quantity is a required input in the form  $LES \leftarrow 4$  if, for example, four satellites are required.

h. Design Type

When low-cost designs are considered, the type of design similarity is identified from the Satellite Synthesis Program. Three types are considered, i. e., communications, navigation, and observation; inputs would be  $LCT \leftarrow 1$  (2 or 3, respectively).

i. Constant Year Dollars

Cost estimates reflect constant dollars, as desired by a particular analysis. The input for 1973 would be  $YR \leftarrow 73$ , i. e.,  $1973 - 1900 = 73$ .

j. Launch Vehicle Type

The cost of launch vehicles is an input to the program (see Table 4-11 ); however, the identity of the Shuttle, the Shuttle and Tug, or any other vehicle must be input, i. e.,  $LVTYPE \leftarrow 1$  (2 or 3, respectively).

k. Schedules

Schedule information (see Table 4-12 ), is useful in visualizing a satellite program and is a necessary input for obtaining time-phased cost streams for use in economic analyses. Input schedules are shown

in three categories. The first, identified by RDT&E, considers design requirements for either the spacecraft or mission equipment (or both), and the year that design or redesign is complete (normally coincident with first satellite launched). Redesigns may occur in a program and can be inputted as partial (e.g., .5) or full depending on the estimated requirements. The second category shows satellite launch schedules, separated by new and (ground) refurbished. As is discussed in Section 4 A, if the payload is to be ground refurbished, the satellite schedules normally must include at least two new satellites so that one can be in orbit while the other is being returned from orbit for refurbishment, otherwise system availability suffers. Finally, the launch vehicle schedule is entered with the number of flights or fractional (shared) flights attributable to each launch vehicle.

For input purposes a series of arrays are needed for each of the input items that are affected. For example, if the number of new satellite launches is two each in 1980, 1982, 1984, and refurbished satellite flights occur at a rate of one per year for the next four years, the array inputs would be:

SSNEW  $\leftarrow$  2 0 2 0 2, 14p\*0

SSREF  $\leftarrow$  5p0, 1 1 1 1, 10p0

In other words, there are 19 places in each array and they must either all be filled in with numbers or with statements that set a group of places equal to a value.

#### 1. Structure Type

This input and those that follow on Table 4-13 are normally not altered and the computer program treats each according to the nominal value noted. Of course, when necessary, these nominal input values are overridden. Type of structure refers either to endostructure (associated with spin-stabilized satellites) or exostructure (associated with less compact 3-axis stabilized satellites with solar arrays). Nominal input is S1  $\leftarrow$  2 for exostructure, because stability type is 3-axis.

---

\* p means next 14 years all have 0 as an input.

m. Stability Type

Nominal input is  $Al \leftarrow 3$  for 3-axis;  $Al \leftarrow 2$  is input for deep space 3-axis system, and  $Al \leftarrow 1$  is input for spin system.

n. First Year of Launch Schedule

For printout purposes the schedule commences with a particular date; 1979 is frequently used because it is a generally accepted date for early Shuttle flight availability. Fiscal rather than calendar years are used because cost streams are geared to fiscal year funding. Nominal input is  $FLYP \leftarrow 79$ . If first launch occurs in another year, that year less 1900 would be the input.

o. Span of RDT&E

This input refers to number of years elapsed between RDT&E commencement and conclusion. Nominal input is  $YRD \leftarrow 3$  (years); depending on satellite complexity it can be varied from two to five years.

p. Refurbish Rate

Not applicable unless satellite is ground refurbishable. The rate applied to the average unit cost gives a cost per flight of repairing and refurbishing a satellite that has been returned from orbit. Nominal input is  $RR \leftarrow .39$  for CDR satellites ( $RR \leftarrow .3$  for LCR satellites).

q. Launch Vehicle Cost

Any type of launch vehicle may be considered; however, the nominal case provides for the use of the Shuttle or the Shuttle and Tug combination. If more than one payload is deployed or serviced on a particular launch, fractional flights may be input. The nominal case is based on \$9.8 million (\$1972) per flight for the Shuttle and \$0.89 million per flight for the Tug; translated to \$1973 these costs are \$10.26 and \$0.93, respectively. If needed, Tug flights may be shown separately by altering the launch vehicle type and the costs per flight.

#### 4. COST MODEL OUTPUT

The payload program model output is designed to show basic RDT&E and unit cost estimates by subsystem and to show the time-phased funding for each major category; RDT&E, investment, and operations by mission equipment, by spacecraft, and by total. These funding categories are included in the output to facilitate economic analyses. RDT&E and unit costs are presented to highlight cost drivers. Total launch vehicle cost (time-phased) is included separately and in the program grand total.


An example has been developed to illustrate the output (and to show the input requirements) for a typical satellite. Tables 4-14 through 4-16 contain example input data; Tables 4-17 and 4-18 show the example output generated by the computer program based on the input data. Table 4-17 contains the basic satellite cost data together with payload, launch vehicle, and total fiscal funding estimates. Table 4-18 provides a further breakdown of these costs into spacecraft and mission equipment funding flows.

Table 4-14 BRAVO Schedule Input - Example

SSRS	←	1, 18p0 <sup>(1)</sup>
SSRME	←	1, 18p0
SSNEW	←	4, 4p0, 3, 13p0
SSREF	←	0 0 1 2 1 0 0 1 1 0 1, 8p0
LVS2	←	4 0 1 2 1 3 0 1 1 0 1, 8p0

(1) 18p0 means the next 18 years all have 0 as an input.

Table 4-15. BRAVO Worksheet - Satellite Cost Estimate  
Basic Input Information

Input Variable	Input Value(1)	Input Description	Remarks
NAME ←	'Example'	Title	Name for Identification
TYPE ←	2	Satellite Type	Current design for reuse, low-cost design
WS ←	373	Structure Weight	Reference expendable weights by subsystem. If satellite is current design reusable (CDR), subsystem weights for reusable design must also be entered (1b). 
WE ←	314	Electrical Power	
WER ←(2)	322	Weight	
WC ←(2)	56	Communications	
WCR ←	64	Weight	
WA ←(2)	147	Stability & Control	
WAR ←	161	Dry Weight	
WAP ←(2)	83	Stability & Control	
WAPR ←	83	Propellant Weight	
WP ←	0	Propulsion Inerts Dry Weight	
WPP ←	0	Propulsion Propellants Weight	
WM ←(2)	240	Mission Equipment	Communication, Earth Resources, etc.
WMR ←	240	Weight	
M2 ←	1	Mission Equipment Type	
E1 ←	520	Init. Elec. Power	Watts

(1) For definition of numerical code see section 3 a-j.

(2) Input variable for CDR-type satellite.

Table 4-15. BRAVO Worksheet - Satellite Cost Estimate  
Basic Input Information (Cont'd)

Input Variable	Input Value <sup>(1)</sup>	Input Description	Remarks
P2 ←	n. a.	Propulsion Type	Solid or liquid, if system needed
P1 ←	n. a.	Propulsion Total Impulse lb/sec	If subsystem needed
C1 ←	1	Orbit Altitude	Low/synchronous or planetary
LES ←	4	No. of Satellites In System	No. of satellites required in orbit for system to operate
LCT ←	n. a.	Design Type (If Low Cost)	If low-cost design is to be considered, the type will be one of three; communications, navigation, or observation
YR ←	73	Constant Year Dollars	e.g., 1973
LVTYPE ←	2	Launch Vehicle Type	Shuttle, Shuttle and Tug, or other

(1) For definition of numerical code see section 3 a-j.

Table 4-16. BRAVO Worksheet - Satellite Cost Estimates  
Additional Inputs\* (Example)

Nominal Input Value	Input Description	Remarks
S1 ← 2*	Structure Type	Nominally Exostructure
A1 ← 1	Stability Type	Nominally 3-Axis
FLYP ← 80	First Year of Launch Schedule	Nominally 1979
YRD ← 3*	Span of RDT&E	3 (Versus 4 Years or More)
RR ← .39*	Refurbish Rate (For Ground Refurbishment)	CDR Nominal is 39 Percent (LCR is 30 Percent)
ALV1 ← 11.19*	Launch Vehicle Cost	Nominally, if LVTYPE = 1, ALV1 = 10.26 LVTYPE = 2, ALV1 = 11.19

\* These inputs are unchanged because they are automatically set at the nominal value.

Table 4-17. Satellite Basic Cost

### EXAMPLE

SATELLITE BASIC COST  
(MILLIONS OF 1973 DOLLARS)

	RDTE	UNIT
STRUCTURE	13	3.01
ELECTRICAL POWER	7	1.36
COMMUNICATIONS AND DATA	6	1.60
STABILITY AND CONTROL	5	1.07
PROPULSION	0	0.00
SPACECRAFT	31	7.05
MISSION EQUIPMENT	9	3.72
SATELLITE	41	10.78
GSE	1	0.00
LAUNCH SUPPORT	0	0.98

[illegible]



Table 4-18. Spacecraft and Mission Equipment Funding Flows

EXAMPLE  
(MILLIONS OF 1973 DOLLARS)

FY	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	TOT
FISCAL FUNDING																								
MISSION EQUIPMENT																								
RDTE	0	0	3	6	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11
INV	0	0	4	9	3	0	0	3	6	2	0	0	0	0	0	0	0	0	0	0	0	0	0	27
OPER	0	0	0	0	0	1	2	2	1	0	1	1	1	1	1	0	0	0	0	0	0	0	0	11
MTOT	0	0	7	15	5	1	2	5	7	2	1	1	1	1	1	0	0	0	0	0	0	0	0	49
SPACECRAFT																								
RDTE	0	0	8	19	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	34
INV	0	0	7	16	6	0	0	5	13	5	0	0	0	0	0	0	0	0	0	0	0	0	0	52
OPER	0	0	0	2	2	2	6	6	3	2	2	4	2	2	2	0	0	0	0	0	0	0	0	35
STOT	0	0	15	37	15	2	6	11	16	7	2	4	2	2	2	0	0	0	0	0	0	0	0	121
PTOT	0	0	22	52	20	3	3	16	23	9	3	5	3	3	3	0	0	0	0	0	0	0	0	170
LV1	0	0	0	0	45	0	11	22	11	34	0	11	11	0	11	0	0	0	0	0	0	0	0	156
TOT	0	0	22	52	65	3	19	38	34	43	3	16	14	3	14	0	0	0	0	0	0	0	0	326

## 5. COMPATIBILITY WITH SATELLITE SYNTHESIS PROGRAM OUTPUT

The primary source of input information for the cost model is the Satellite Synthesis Program. With the exception of NAME, TYPE, LES, YR, LVTYPE, FLYP, and schedules, all cost inputs needed for any particular case will be found in the synthesis output. Accordingly, wherever possible the payload cost model and the synthesis model have used the same program coding to facilitate identification and transfer of input data. For example, WS identifies structure weight under REFERENCE WEIGHTS, CDR GROUND REFURB, or LCR and it also identifies the cost input for structure weight. WE similarly identifies electrical weight; however, if the satellite is CDR the WE cost input will be found in the REFERENCE WEIGHT column and the WER cost input will be found under the CDR GROUND REFURB column. (Recall, however, that for LCR designs the weights to use are REFERENCE WEIGHTS.) Two synthesis outputs (cost inputs) are not as easily identified. The first, mission equipment type (cost input M2) is identifiable as NAV, COM, or OBS under TYPE MISS. EQUIP. If the satellite type is a low-cost design, it also identifies the value to use for LCT, the second input. All other cost input codes needed are the same as the synthesis outputs.

The other cost inputs mentioned above are obtainable from either the capture analysis (refer to Section D 1) or from the facts surrounding the case to be studied. NAME, TYPE, LES and YR generally are known from the case itself. LVTYPE, FLYP, and schedule information should be obtainable from the capture output.

## F. SPACE SYSTEM OPTIMIZATION, RISK, AND LOGISTICS ANALYSIS

### 1. INTRODUCTION

When a normal analysis gets to this point, there will be several problems which remain to be solved in order to arrive at an optimized solution and be assured of meeting the system outage requirements. All satellite systems have been configured to meet the functional requirements. The problem then is to establish an optimum configuration (for lowest cost) by choosing between the alternative satellite design approaches and satellite design life (mean mission duration) options and to decide how many spare satellites are required on orbit. This is accomplished by completing the analyses of all reasonable approaches and quantizing the tradeoffs.

The satellite design alternatives available from which to choose would normally include current design satellites suitable for ground refurbishment, or current design satellites suitable for on-orbit repair (or ground refurbishment), or low-cost satellites suitable for on-orbit repair (or ground refurbishment). The two current design satellite approaches would normally have three or four mean mission duration designs from which to choose. (Such variations in mean mission duration are obtained by changing satellite component redundancy.) Another option available to the analyst is to add spare satellites on orbit for any of these configurations.

Since all satellite systems meet the functional requirements, the problem becomes (1) selecting the satellite systems which meet the risk (outage) requirement and eliminating those which do not; (2) determining which of the satellite systems that meet the risk (outage) requirements show the lowest system cost estimate; (3) of those configuration alternatives which display the lowest cost estimate or are close to it, which ones exhibit outage which is the least sensitive to launch, delays, and satellite failure rates; and (4) for the satellite system selected from the above considerations, what is the satellite traffic required to maintain the space capability on orbit (logistics).

## 2. PROCEDURES

The calculations required to carry out the method of analysis appropriately have been coded as an interactive computer program called RISK using the APL program language. Therefore, the methodology is best described by the computer program itself. The computer program accepts input data for each of the space system alternatives which are mentioned in the introduction. The output tabulated numerically quantifies the availability (1 minus the outage), program cost estimate, and expected number of launches for each of the alternative configurations as a function of (1) launch delay for replacement of or on-orbit repair of a satellite, (2) satellite failure rate, (3) satellite turn-on delay for on-orbit spare satellites, (4) satellite preventative maintenance launch interval, and (5) a launch-on-warning strategy instead of the launch-on-failure logistics strategy. The methodology is a very complete simulation of satellite system logistics which also sums the program costs and number of launches required for each simulation.

After the operation of the computer program, the quantitative results are then plotted so that the system tradeoffs are displayed and the selection procedure described in the introduction is accomplished. An example of this procedure is shown in section 4.F.2.d.

### a. Inputs

The inputs for the computer program consist of the cost estimates for each satellite to be studied; unit costs, satellite development costs, satellite operations costs, and transportation cost estimates are included. The configuration of satellite equipment and the associated failure rates for every identified element of each satellite are also inputs. An alternative input would be the estimated survival curve for each satellite. The probability of mission completion for the Shuttle and upper stage (if the latter is used) and an estimate of the infant mortality satellite loss factor are used.

Inputs for the subject APL computations are of two kinds familiar to APL terminal operators:

(1) Global Variables

Global variables are constants which are stored in the common APL workspace under distinctive alphanumeric code names, and which are available to any executing program within the same workspace, provided that the code name used has not also been previously declared "local" within the executing program. Global variables may be left as constants throughout the computations, such as numerical tables giving the failure rates for a set of modules. However, they may also be purposely modified by the computations of the program during its execution; this is not normally done to variables which are intended as inputs in subsequent executions of the same main program. Thus, as many different inputs as desired may be stored permanently as global variables for multiple executions of the same program, or they may be purposely changed before an execution as a means of varying the input data or program parameters.

(2) Interactive Inputs

One of the main purposes of such computer facilities as APL is the interaction between computer and terminal operator in flexible computations, using a dialog between them as a means of allowing the operator to make decisions as to data inputs or program execution. In both cases, a program must have been stored previously which causes the computer to interrogate the operator, asking for the precise information needed at the moment.

Both of the above forms of input are used in the BRAVO APL computations.

Global inputs are used primarily as a means of storing all of the computational data and program parameters which will be used over and over as many different cases are computed. They could be "hard-programmed" into the programs, but that is a much more difficult form of input to alter purposely than global variables.

Interactive inputs are used as a convenient means of setting up the input data for different cases of interest. This is done in the APL subroutine **SETUP**, which then immediately causes execution of the remainder of the program.

Table 4-19 shows the required inputs for the BRAVO logistics analysis program.

b. Computer Program Listing and Flow Chart

The APL functions (program listing) is presented in Part 4 of this volume of the final report. It is intended that the flow charts described in the next section should be used for tracing the order in which the computations occur in the computer program. The copies of the APL functions themselves are only required to set up the program on the computer or if the details of the algorithms are needed by the analyst. It is assumed that the analyst will have available to him or his computational aide an IBM APL terminal for carrying out the calculations.

Once several input variables have been defined in the APL "workspace," the entire program of computations is executed by typing in the name of the APL function **SETUP**, which is the beginning flow chart. **SETUP** allows initializing several other program parameters and variables, and then automatically executes the function **INTELSAT**. The remaining functions are executed as branches within **INTELSAT**.

Since the art of flow-charting is not perfectly defined, these flow charts were drawn by adapting some of the conventions used in FORTRAN flow charting, sometimes using FORTRAN conventions not actually followed in APL programming. The flow charts are meant to show the intent of the algorithms rather than their actual mechanization, so that one is justified in taking some liberties with the conventions. For example, APL branches to other APL functions by merely using the function name (with proper input syntax), whereas FORTRAN must use a "CALL"

Table 4-19. Inputs for BRAVO/APL Reliability/Cost Computations

<u>Global Inputs</u>		
YES	=	1
NO	=	0
DT	=	Integration interval width (usually 3 months)
TAVEC	=	A vector of turnaround time for dormant spares
TP	=	Program time in months
OSP	=	A vector, no. of orbital spares in each position
SREQ	=	A vector, no. of satellites required in each position
Q	=	Q-factor
DUTY	=	Duty cycle
TU	=	Time unit
<u>L</u> AM	=	A vector of failure rates for the system modules
NMAT	=	A table (matrix) showing various system configurations
RINF	=	1 - probability of satellite infant mortality
ROOS	=	Tug reliability
REOS	=	Shuttle reliability
RNPT	=	No. of communication repeaters per satellite
rmod	=	A vector showing reliability model for each satellite module
X	=	1 less than no. of repeaters needed for success
FD	=	Factor of dormancy for spare satellites
CEOS	=	Cost of Tug
COOS	=	Cost of Shuttle
GSP	=	No. of ground spares

Table 4-19. Inputs for BRAVO/APL Reliability/Cost Computations (Cont'd)

Global Inputs (Cont'd)

HVEC	=	Vector of launch turnaround times
SPACE	=	A printing format variable
MODNAME	=	A character matrix containing the module names for printing the system failure rates and configuration data

Interactive Inputs (in SETUP)

CONFIG	=	Choice of different satellite
SVPR	=	Decision whether to print satellite input data
RPRINT	=	Decision whether to print reliability, MMD, and satellite failure rates
NEEDTUG	=	Decision whether or not a Tug is needed in addition to the Shuttle
TR	=	Scheduled revisit time in years, integers up to 7
H	=	Fixed launch delay time in months; must be a member of the set HVEC
TS	=	Spare activate time in days; must be a member of the set TAVEC
LAMFAC	=	Proportional multiplier for the system module failure rates, <u>L</u> AM
CPRINT	=	Decision whether to print costs
BASEYEAR	=	Calendar year on which costs are based
CRM	=	Refurb cost multiplier in percentage of original cost of an item
ENPRT	=	Decision whether to print out expected numbers of satellites



command, passing inputs and receiving outputs through the "CALL."  
It was decided to represent such APL branching by representing it as a FORTRAN subroutine call, although the actual call and computation sequence could be quite different.

The general conventions used are as follows:

- (1) A circle is used for start and end of a function execution.
- (2) A large triangle with a number in it is used when the function charted must be continued to another page; another triangle with the same number on a succeeding page shows where the flow chart continues.
- (3) A rectangle or square is used primarily to show computations of various sorts. This includes function calls, which then branch out of and return to the calling function block.
- (4) Input and output are represented by boxes with rounded corners or semicircular ends. The inscription in the box indicates whether it is input or output.
- (5) Decisions are indicated by diamonds (lozenges), to show the use of some supplied or computed criterion for computations or for branching within the APL function.
- (6) Since APL has an interactive capability in which the operator must supply inputs upon request, the APL "quad" operator,  $\square$ , is shown at various places in the flow chart where they occur in the algorithms.
- (7) APL has various other notational features which provide a powerful and concise mathematical language not found elsewhere. Since it is impossible to represent some of these features in more conventional mathematical language without greatly expanding the algorithms, and since it is expected that only persons fairly familiar with the APL language will be involved in using these APL functions, many of the computational boxes include somewhat abstruse APL "equations." However, in the interest of clarity, parentheses have been added to group computational terms in a manner not actually required by APL conventions; hence, some of the algorithms of the flow charts will not appear to be the same as those of the actual APL functions.

- (8) In the flow charting, any APL commands having to do only with the formatting of the printout have been omitted as being extraneous to the intent of the flow charts. Specifically the use of the functions DFT, SP, and LI are not shown at all in the flow chart, but these functions are necessary for the successful execution of the program.

The flow charts are shown in Figures 4-25 through 4-55.

c. Procedure for Modification of APL Computer Program

The methodology coded in the APL computer program is set up to analyze an output data appropriate for the Intelsat IV satellite system. As coded, the program can be made useful for any satellite system having the following characteristics in addition to the normal 7-satellite Intelsat IV system:

- (1) Single satellite on orbit
- (2) Single satellite on orbit plus one spare satellite on orbit
- (3) Two satellites on orbit, both of which are required for successful operation
- (4) Two satellites on orbit, both of which are required for successful operation plus one spare satellite on orbit backing up the aforementioned two satellites.

Cases 1 through 4 above can be represented by inputting the satellite system data in a normal fashion but selecting the output data for the "Pacific" area for cases 1 or 2 and for the "Atlantic" areas for cases 3 or 4.

If the analyst desires to modify the APL computer program, for instance a navigation system or other multiple satellite system problem, he may do so by following the procedures exemplified below.

The description of the risk analysis in its present form is non-committal about how the input data got into the various storage locations. The fact is that the necessary global variables were named and inputted manually from the keyboard without a formal interactive program to assist

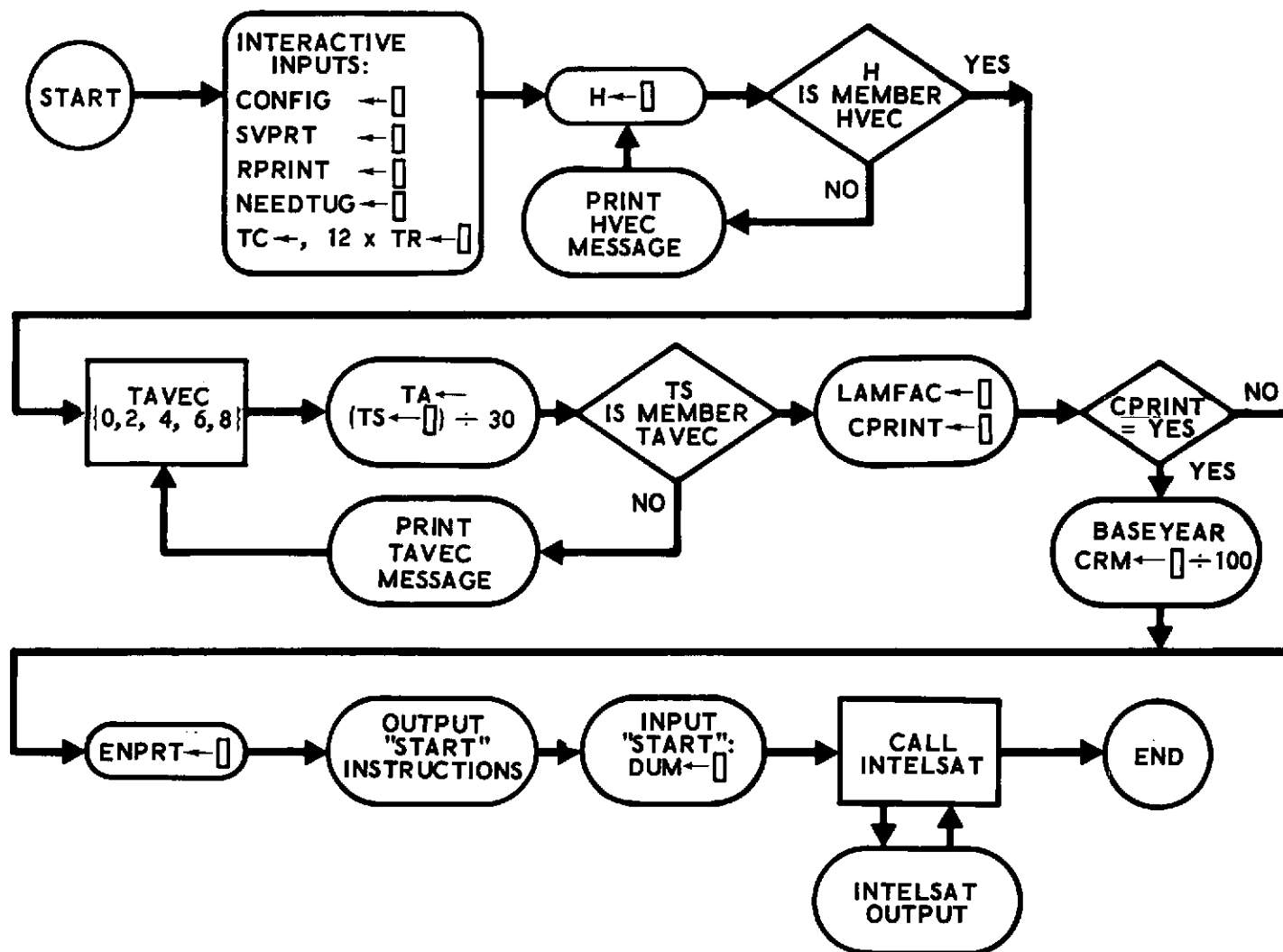


Figure 4-25. SETUP Flow Chart

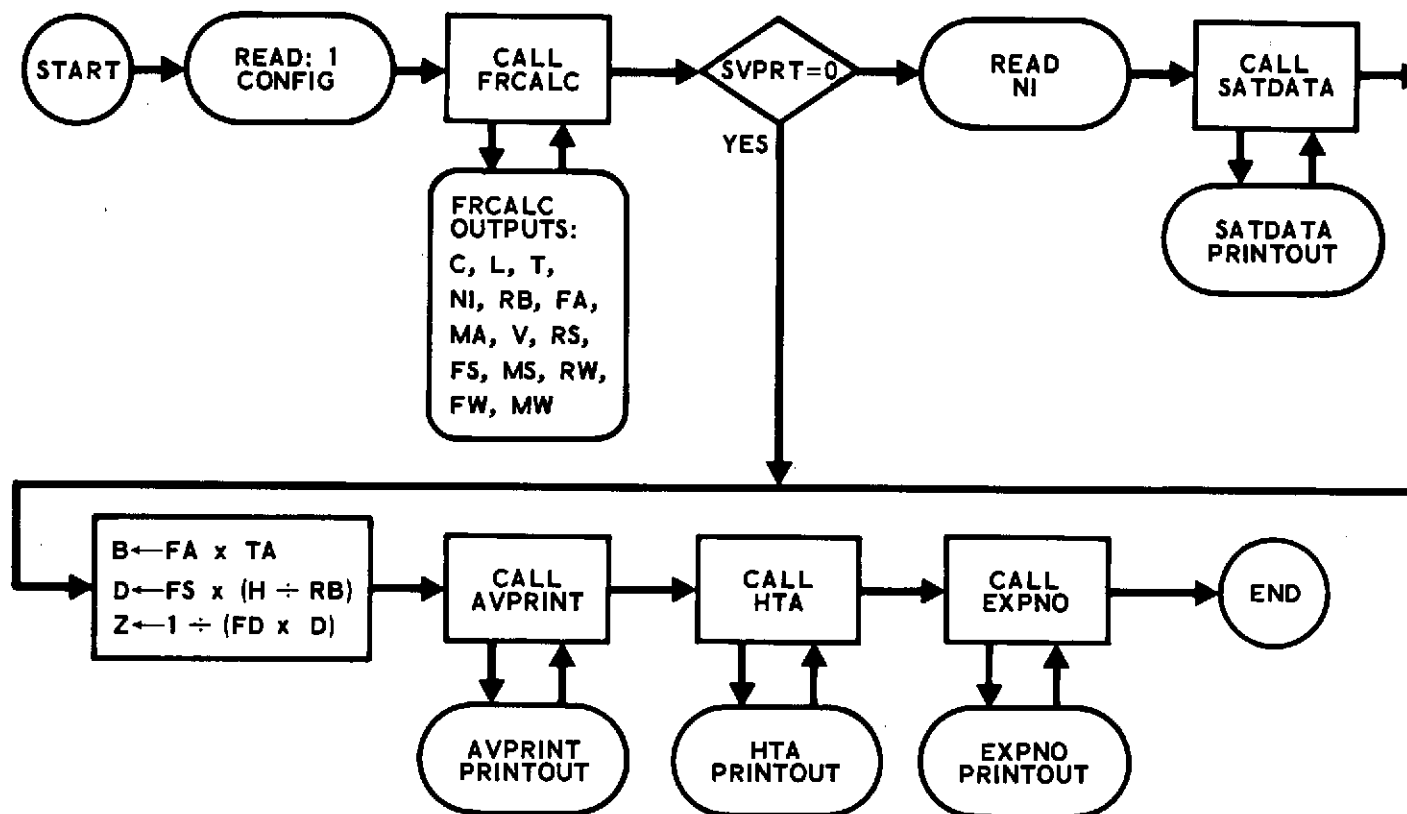


Figure 4-26. INTELSAT Flow Chart

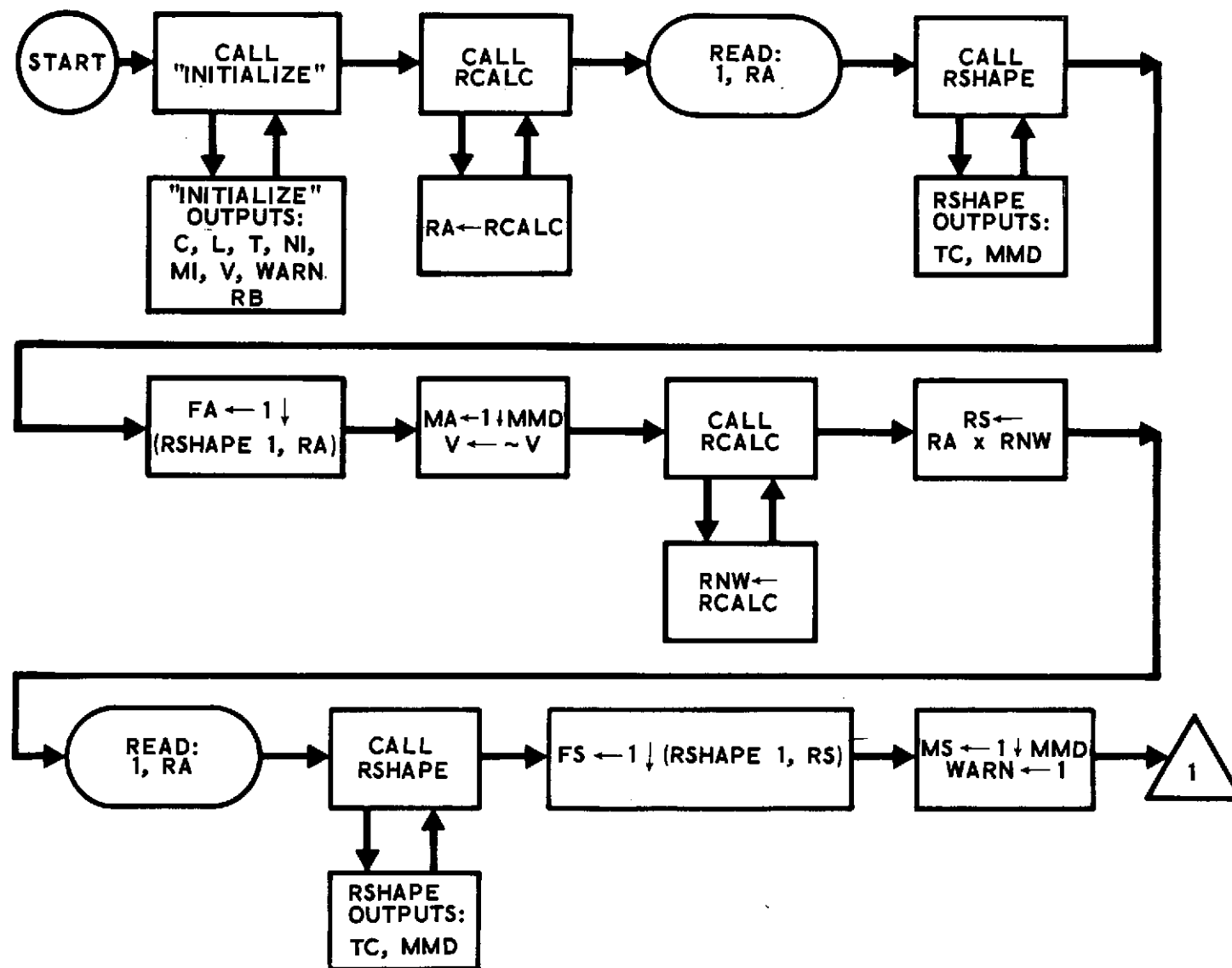


Figure 4-27. FRCALC Flow Chart

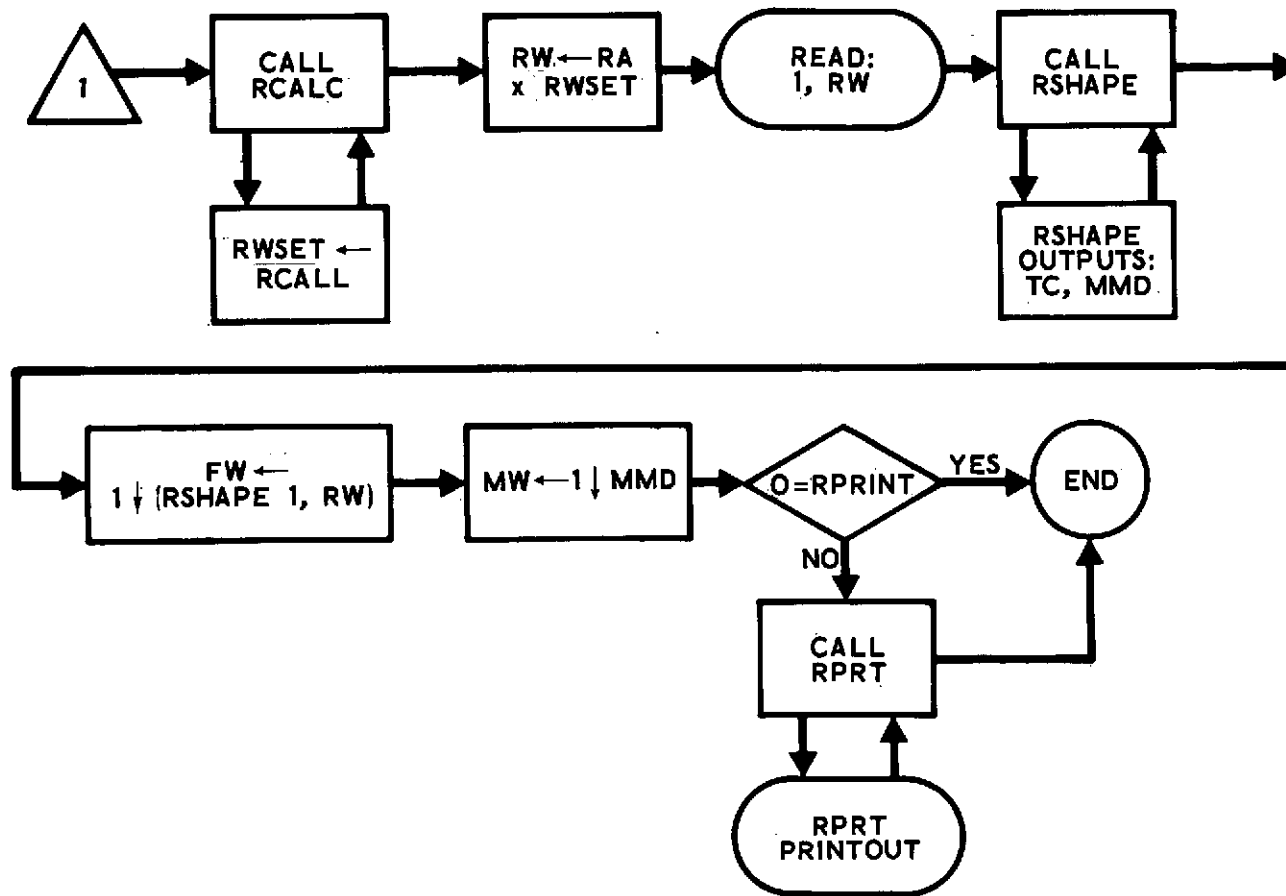


Figure 4-27. FRCALC Flow Chart (Cont'd)

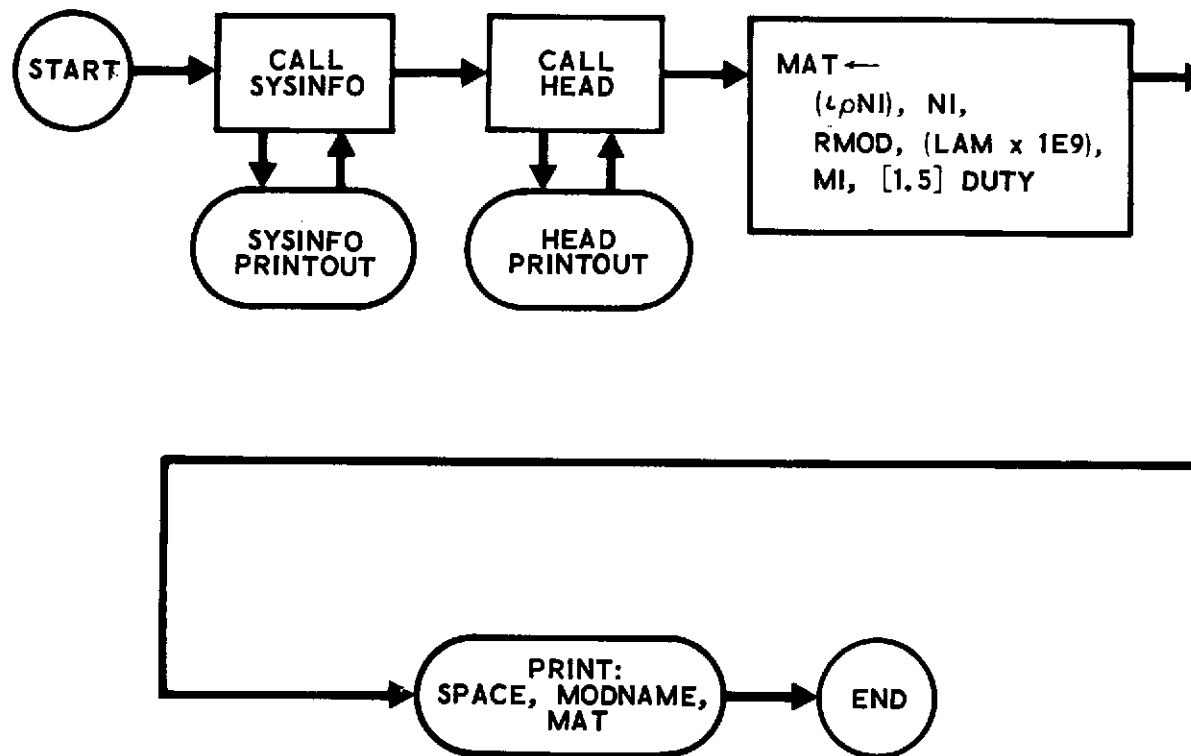


Figure 4-28. SATDATA Flow Chart

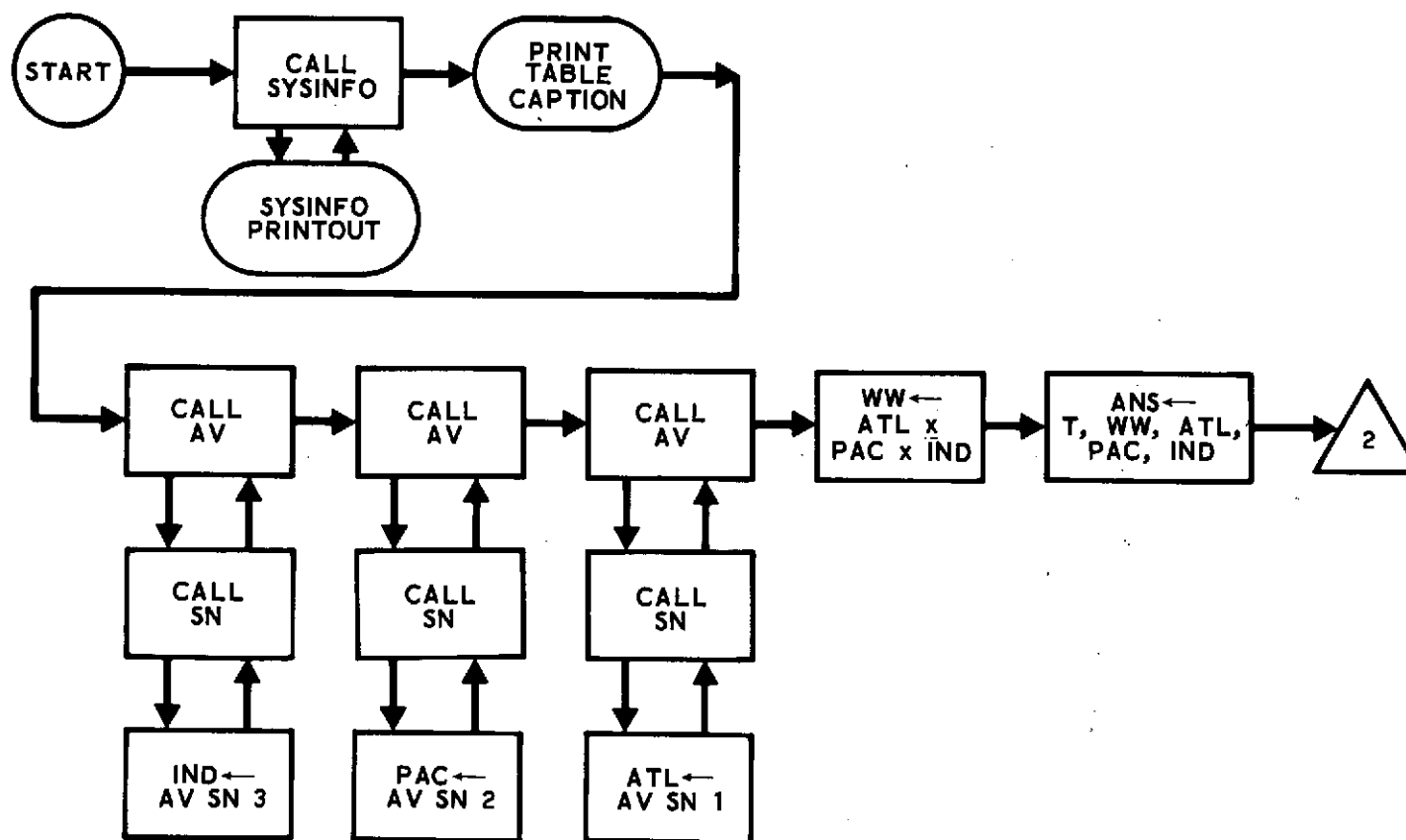


Figure 4-29. AVPRINT Flow Chart



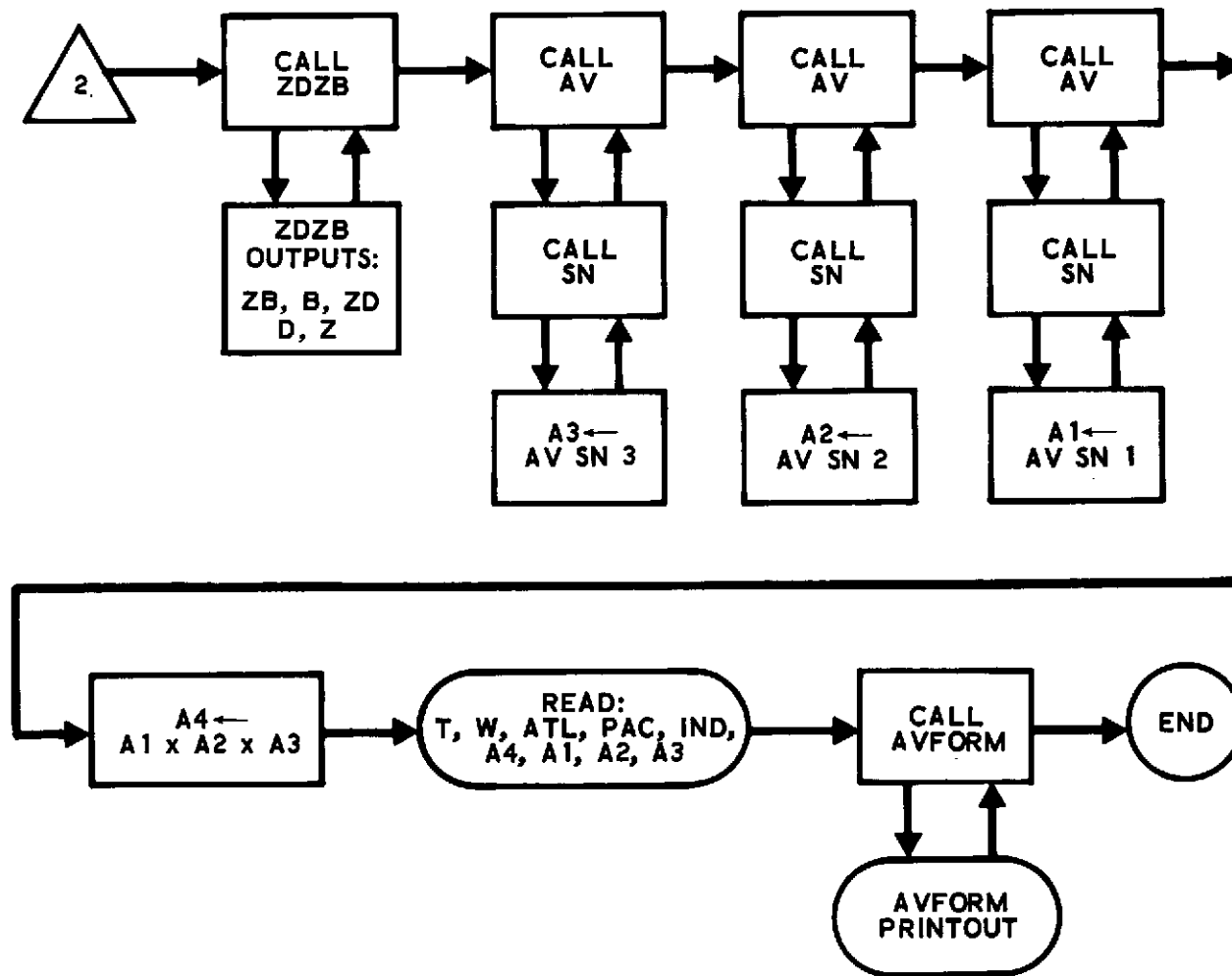


Figure 4-29. AVPRINT Flow Chart (Cont'd)

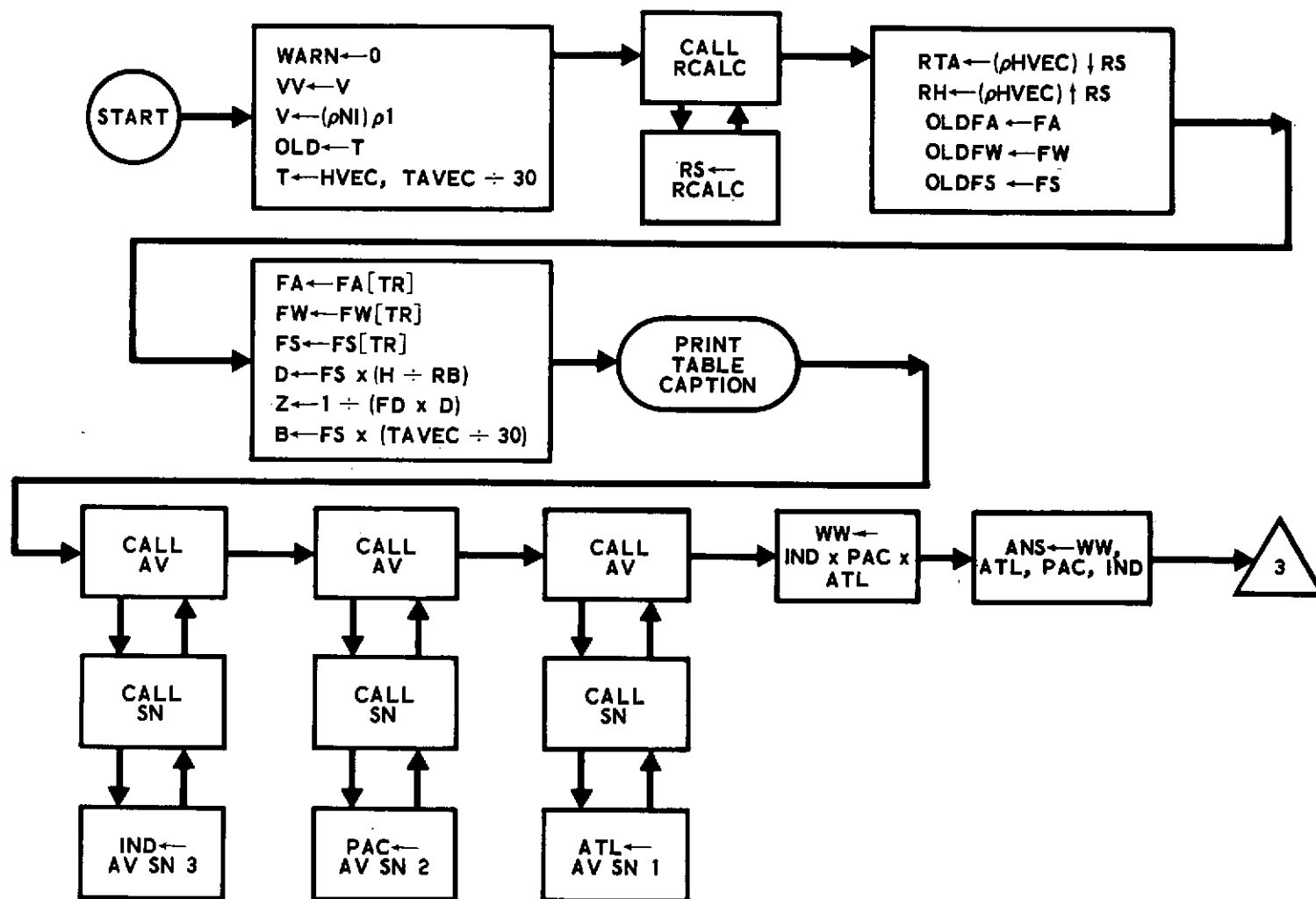


Figure 4-30. HTA Flow Chart

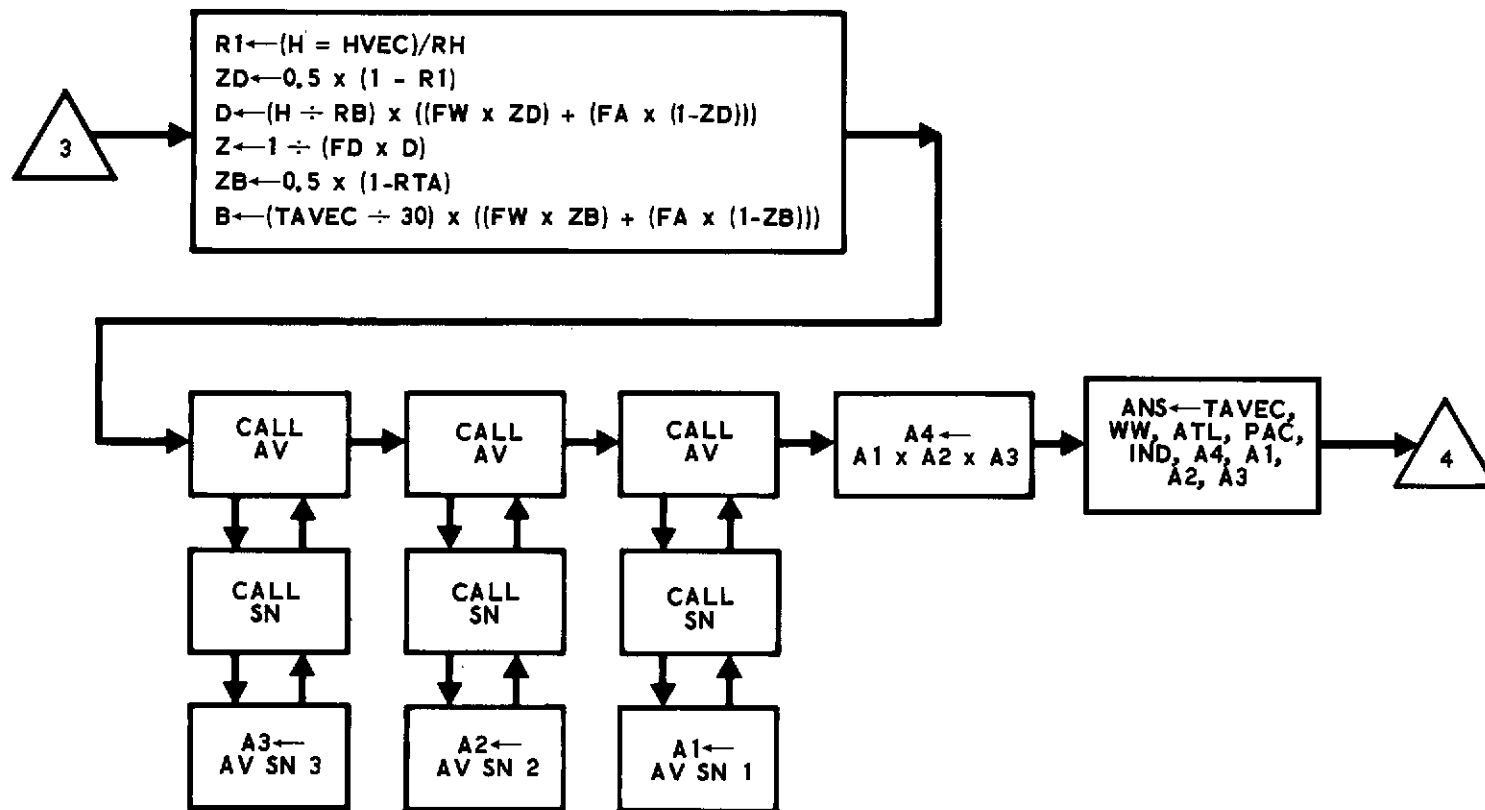


Figure 4-30. HTA Flow Chart (Cont'd)

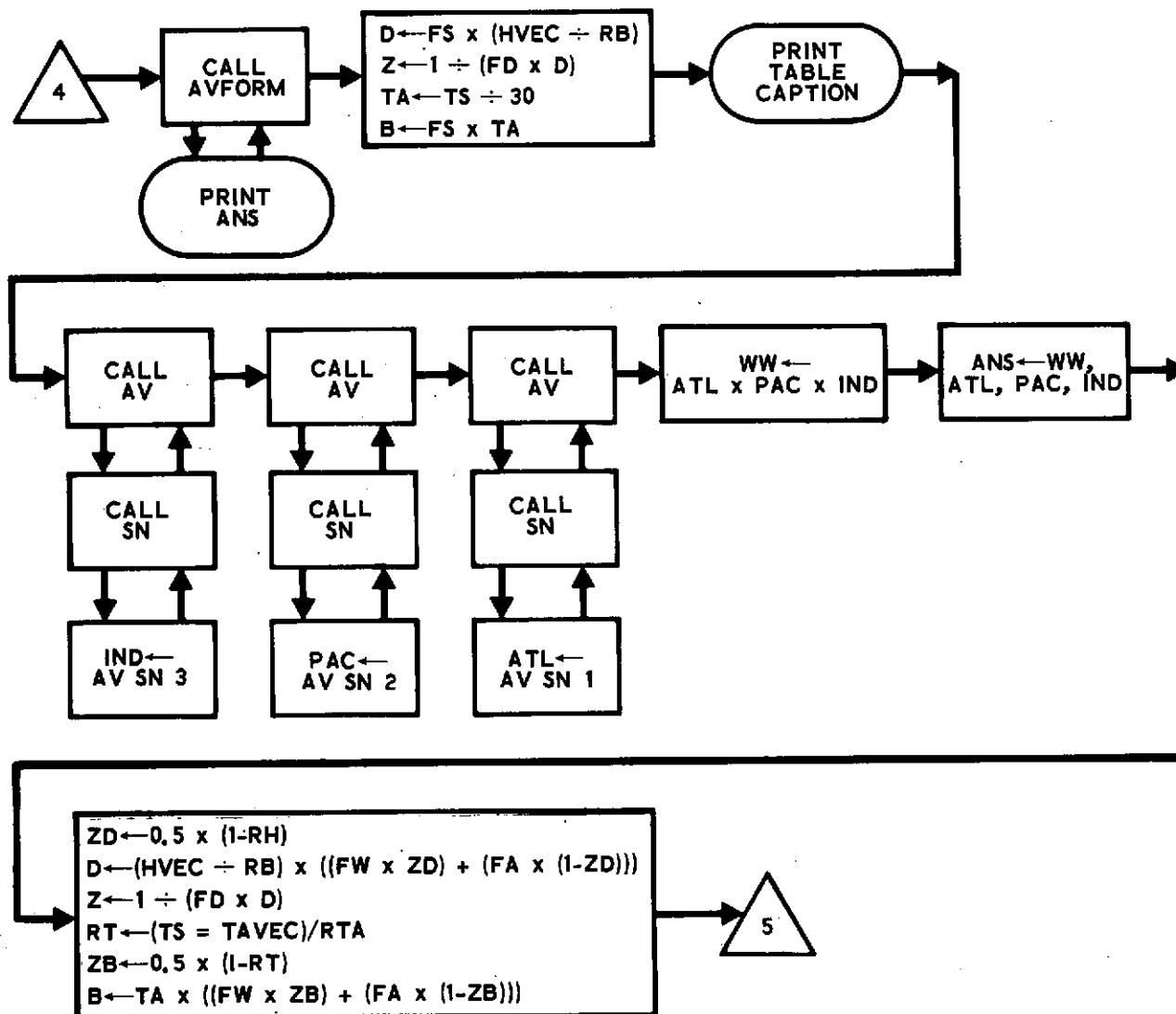


Figure 4-30. HTA Flow Chart (Cont'd)

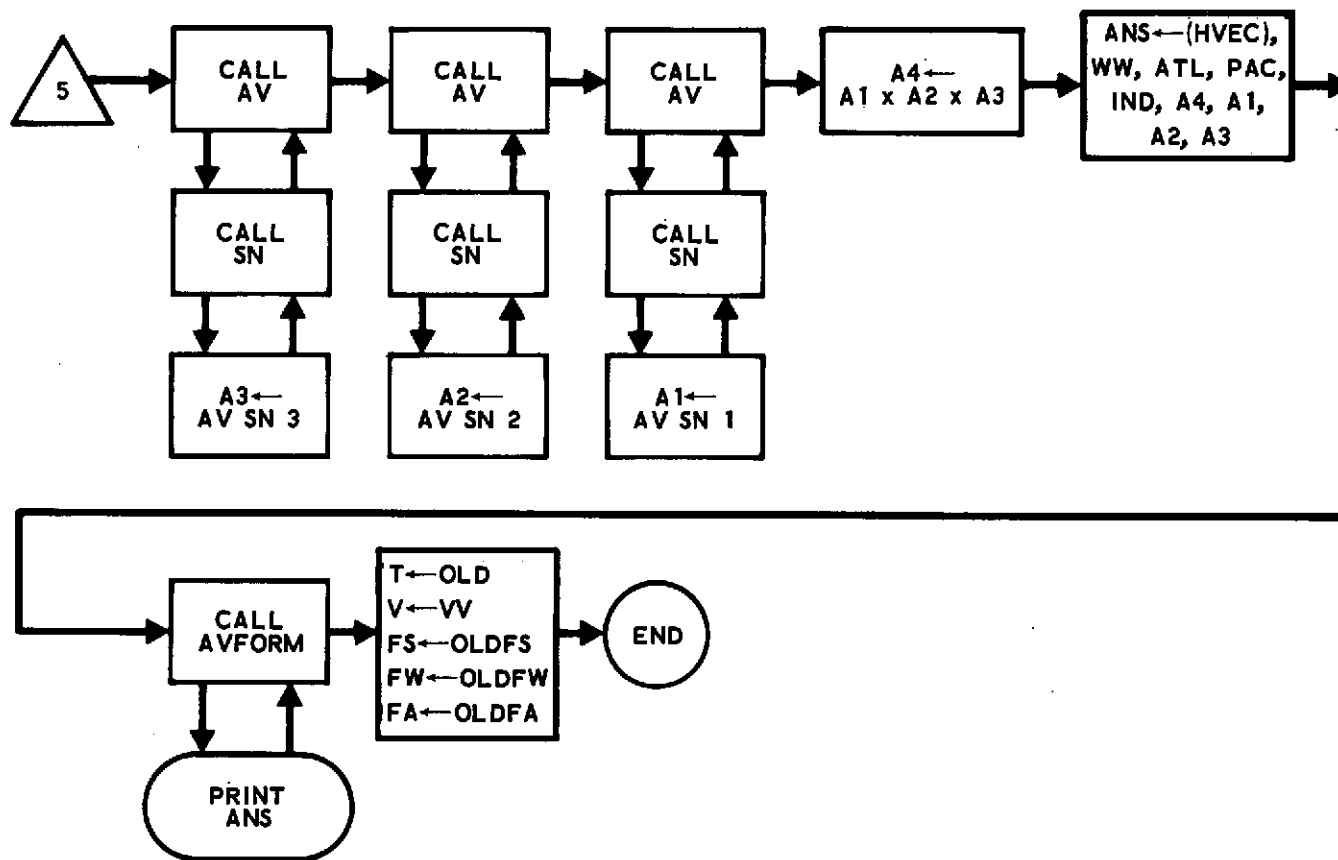


Figure 4-30. HTA Flow Chart (Cont'd)

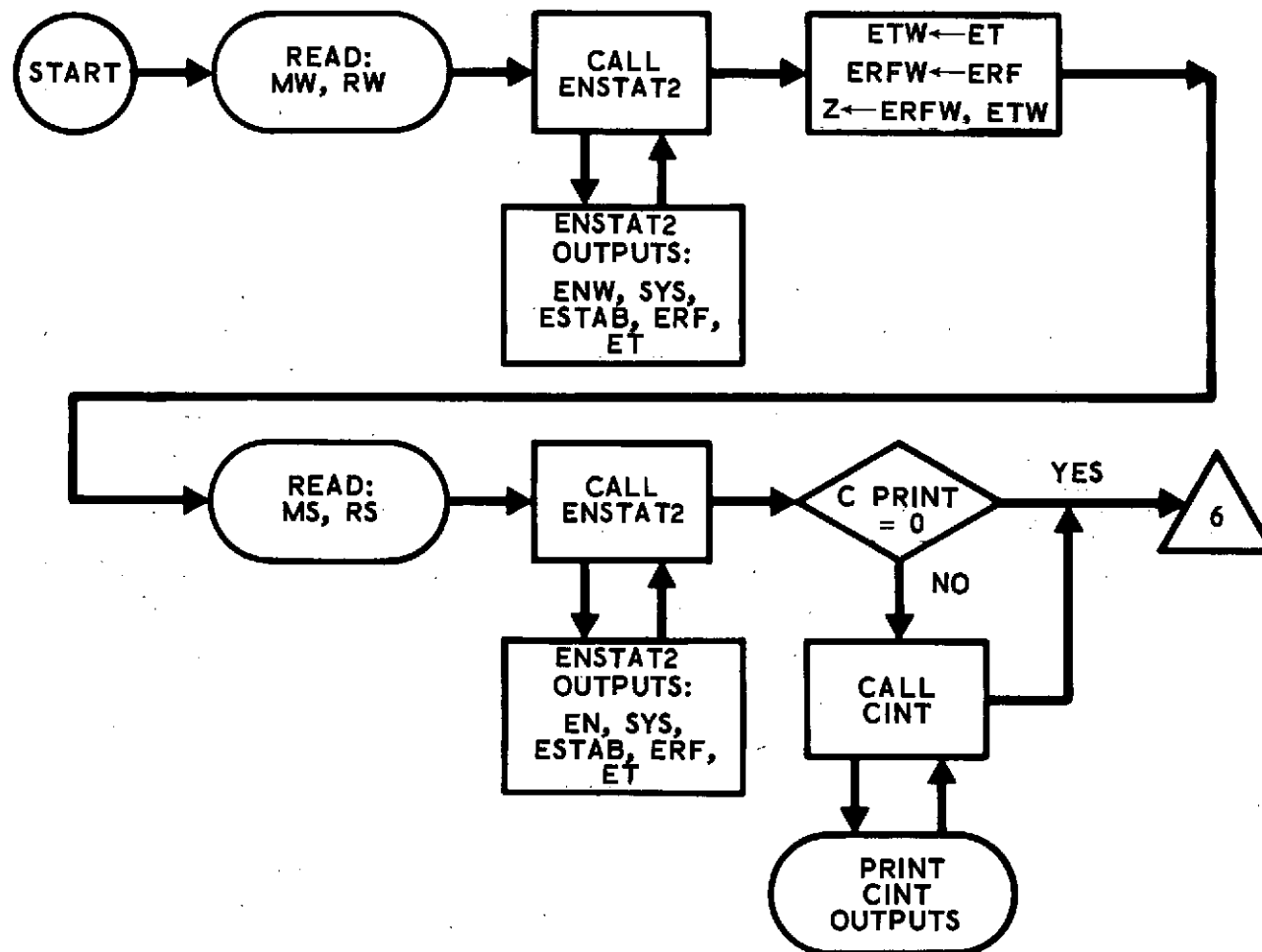


Figure 4-31. EXPNO Flow Chart

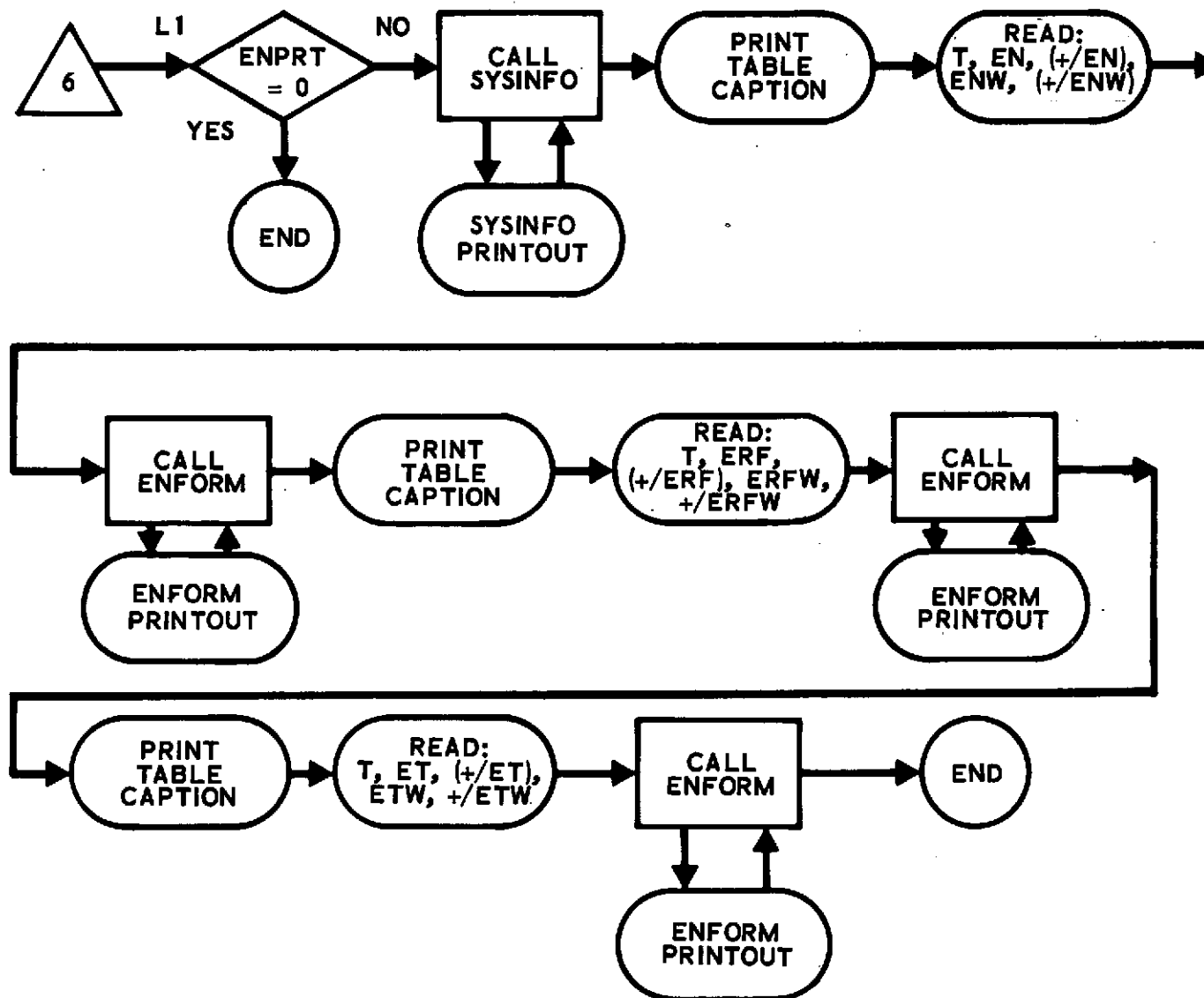


Figure 4-31. EXPNO Flow Chart (Cont'd)

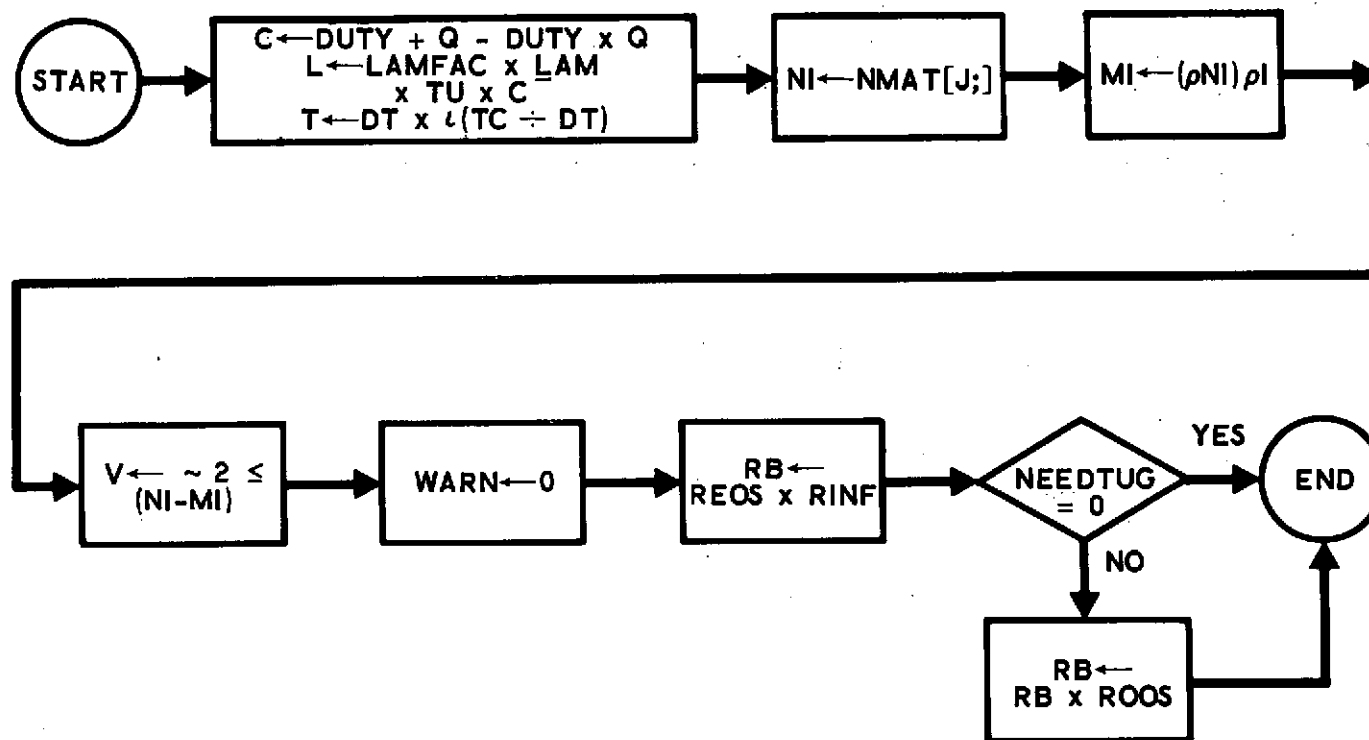


Figure 4-32. "Initialize" Flow Chart



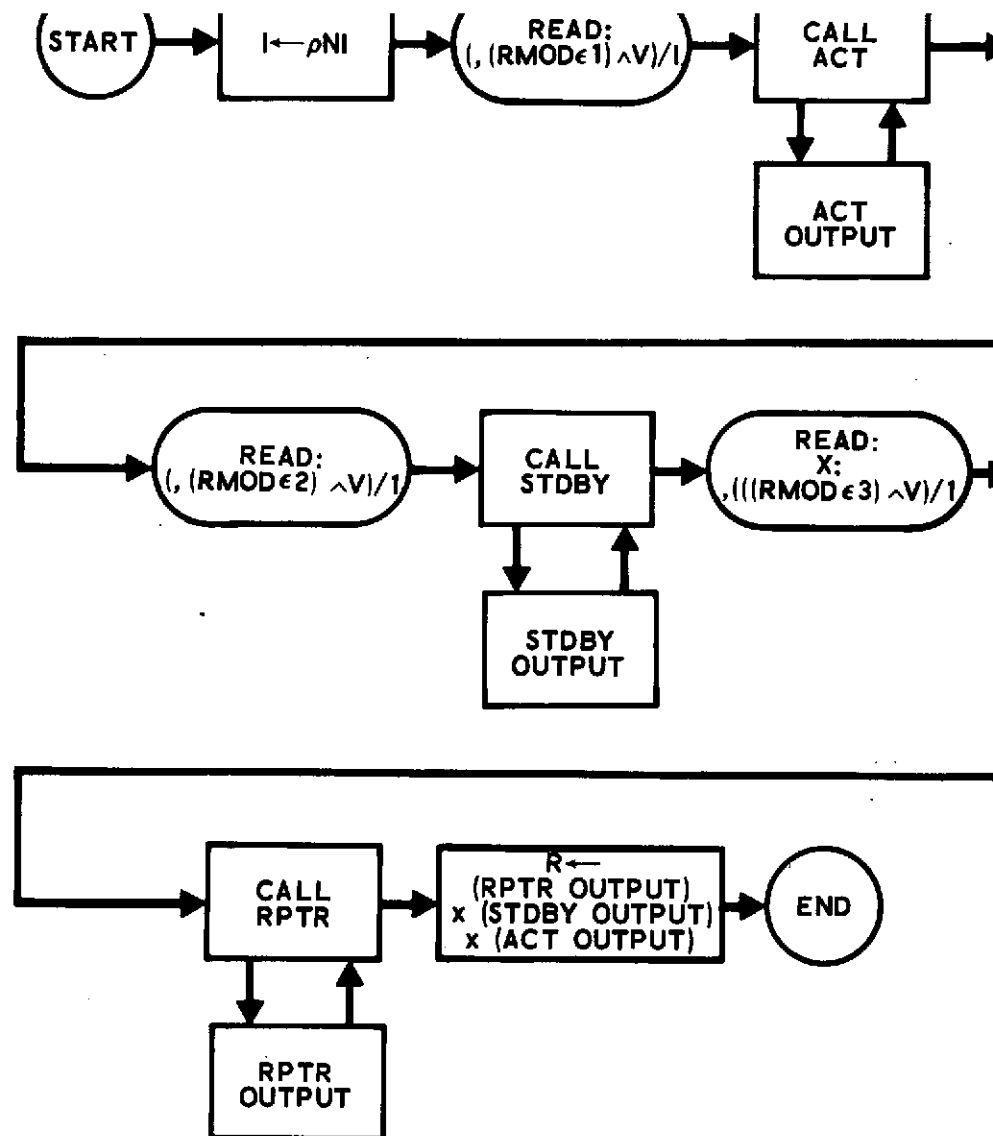


Figure 4-33. RCALC Flow Chart

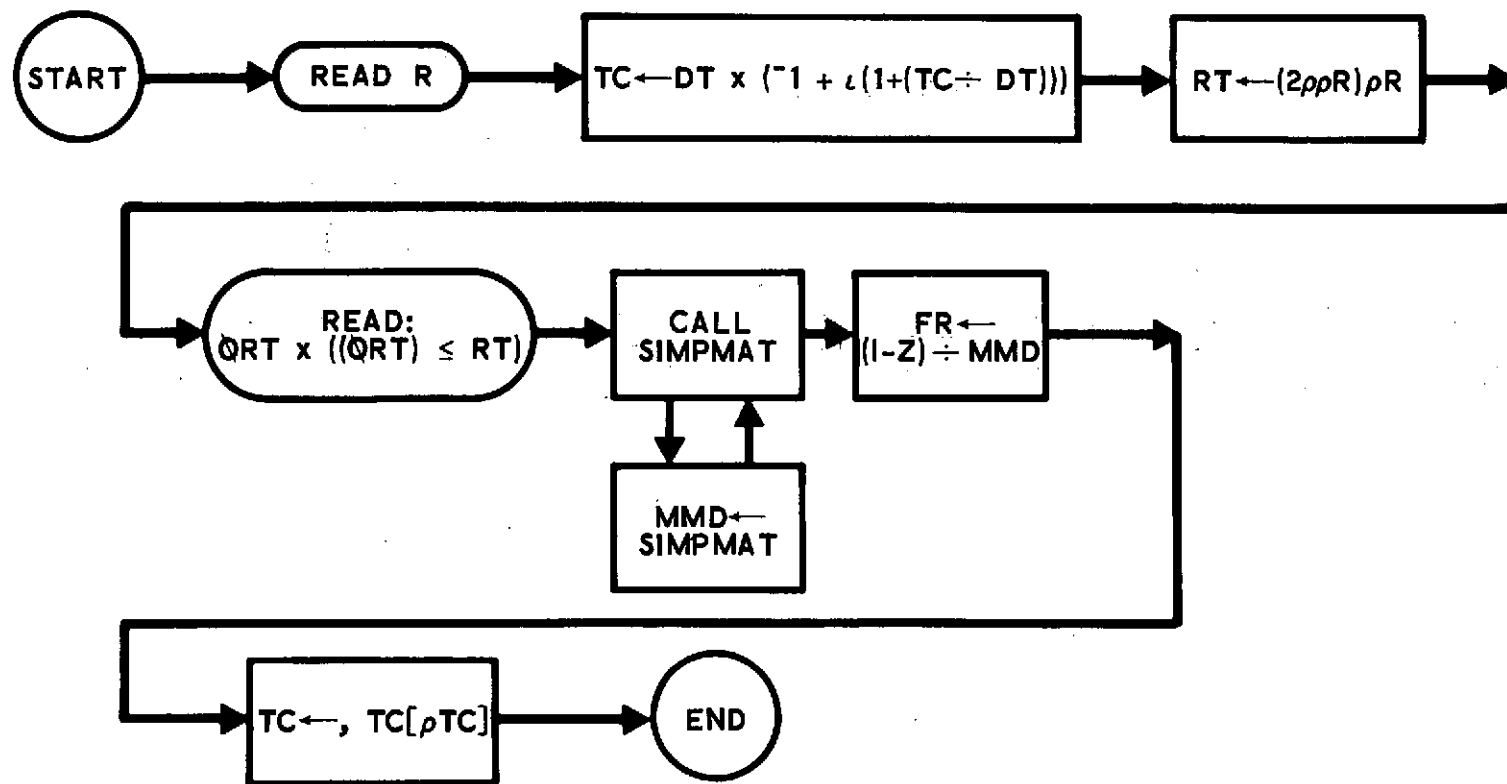


Figure 4-34. RSHAPE Flow Chart

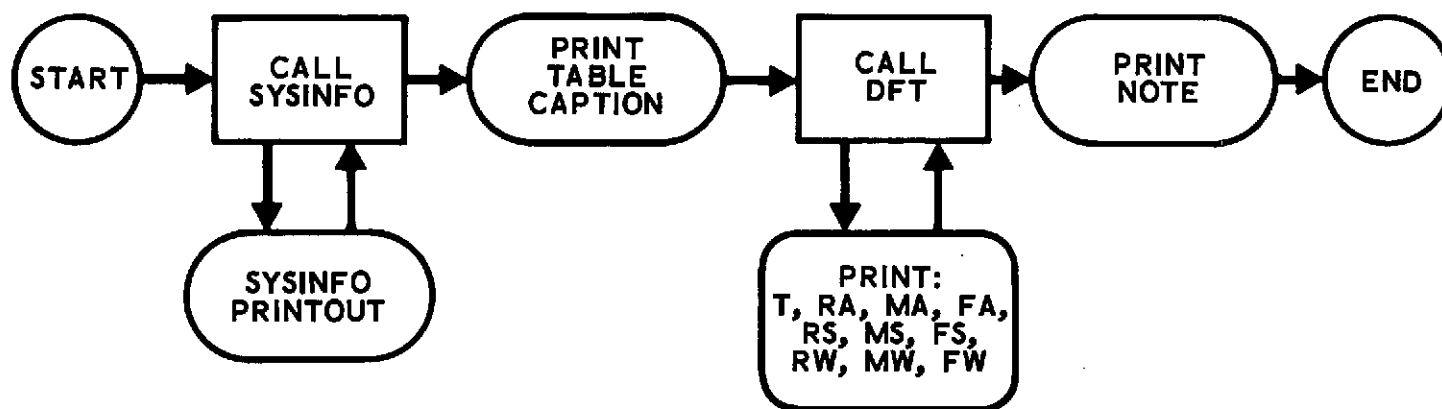


Figure 4-35. RPRT Flow Chart

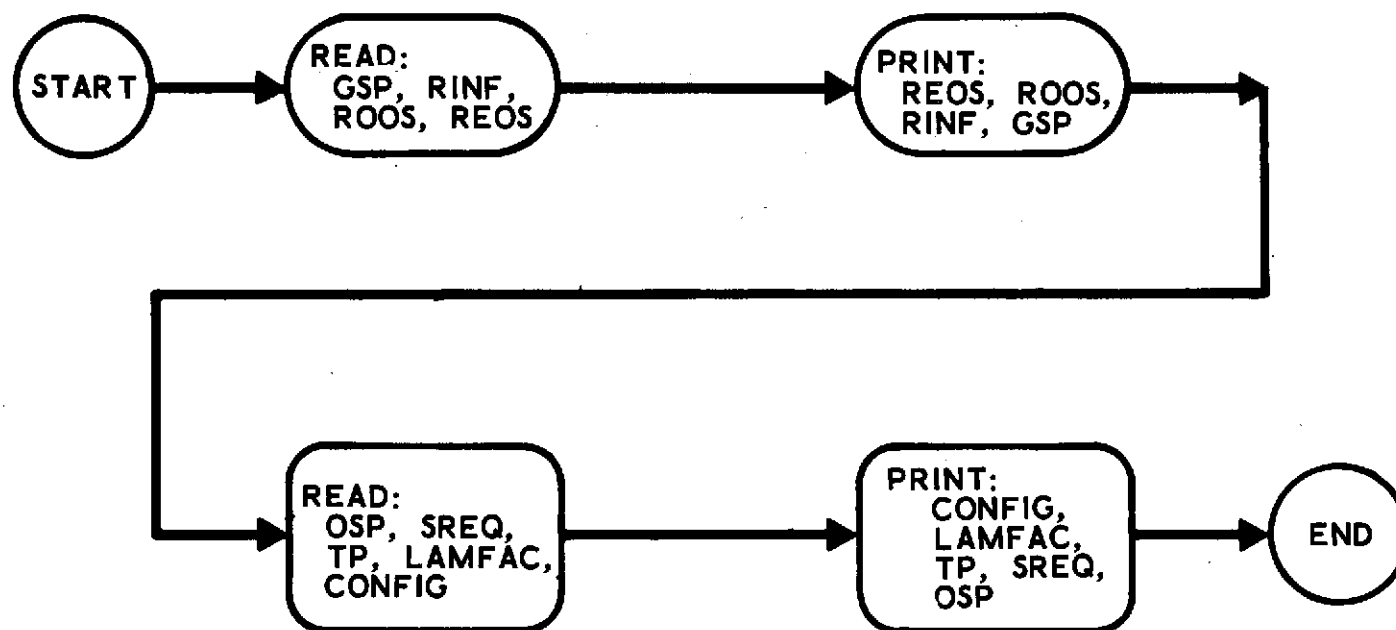


Figure 4-36. SYSINFO Flow Chart

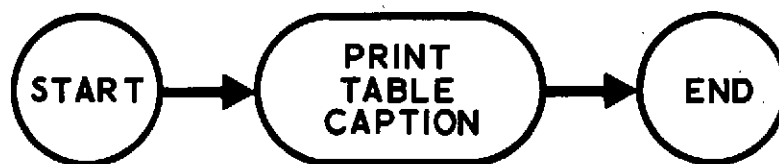


Figure 4-37. HEAD Flow Chart

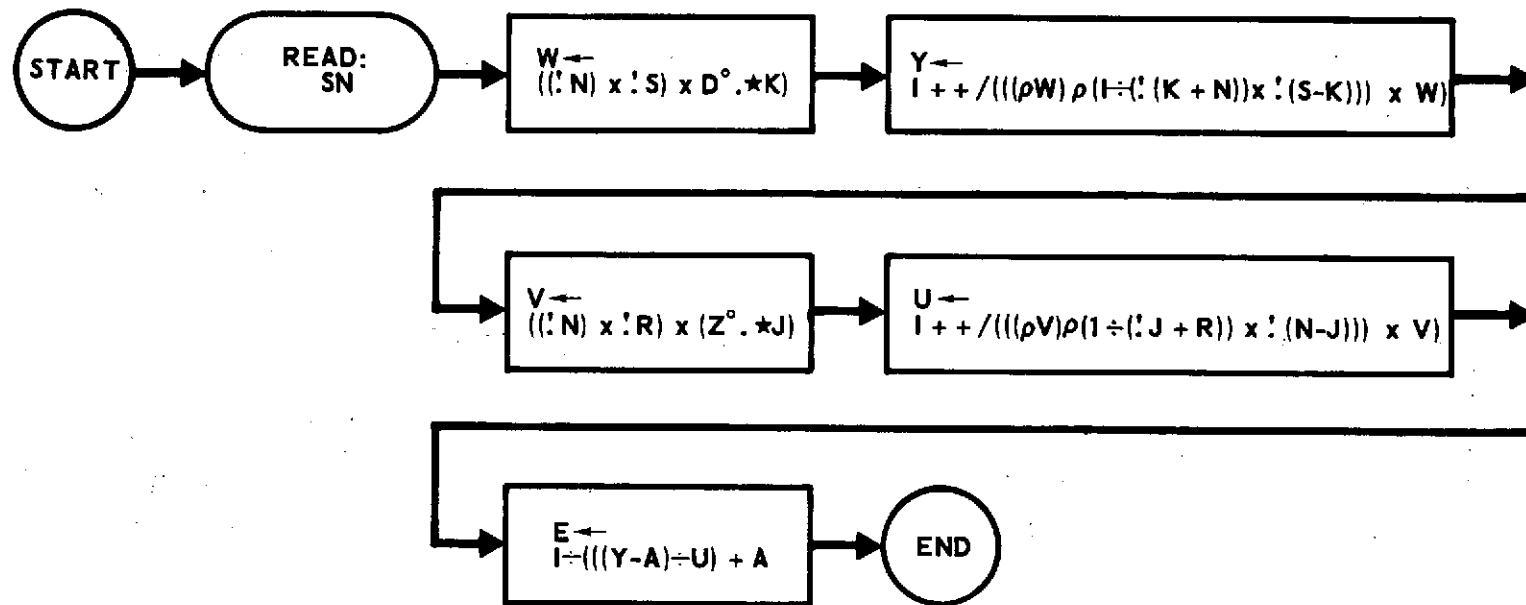


Figure 4-38. AV Flow Chart

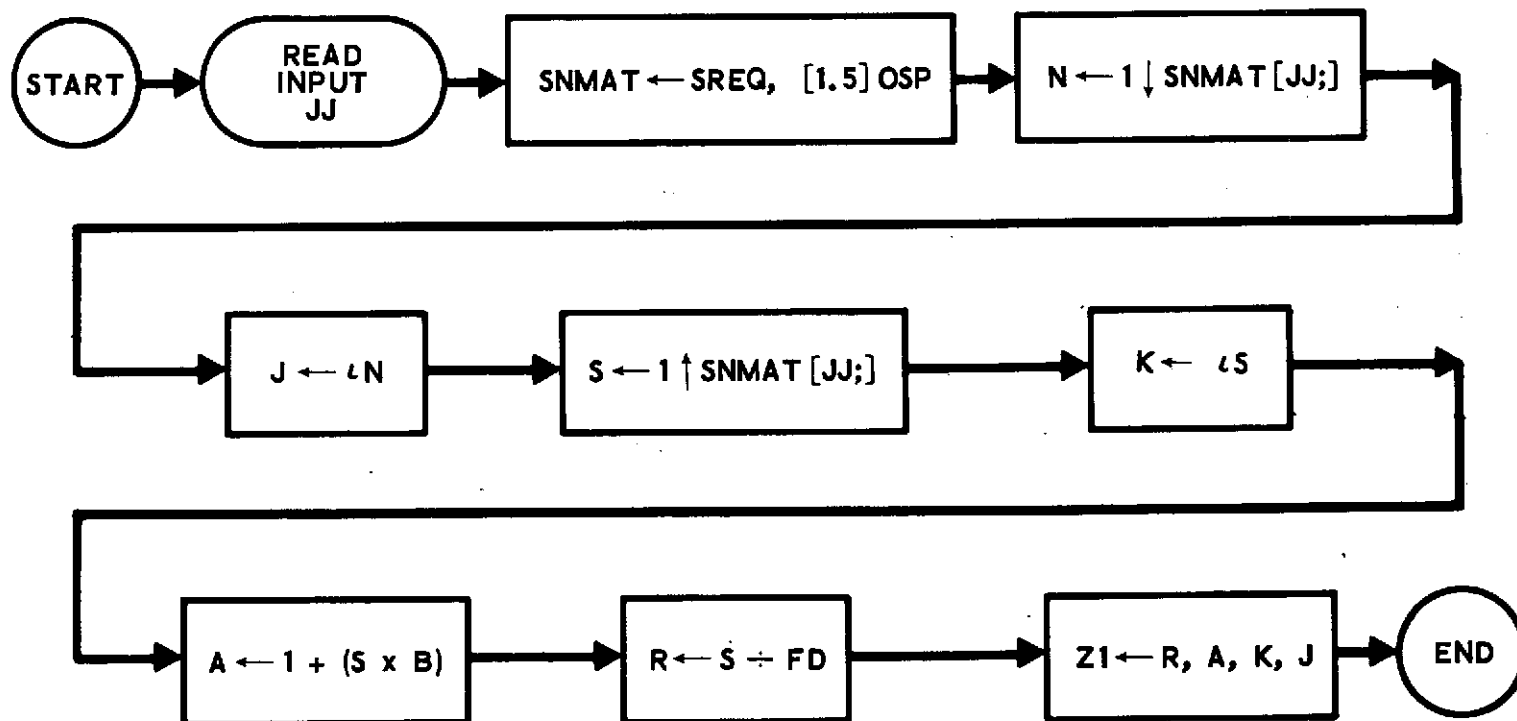


Figure 4-39. SN Flow Chart

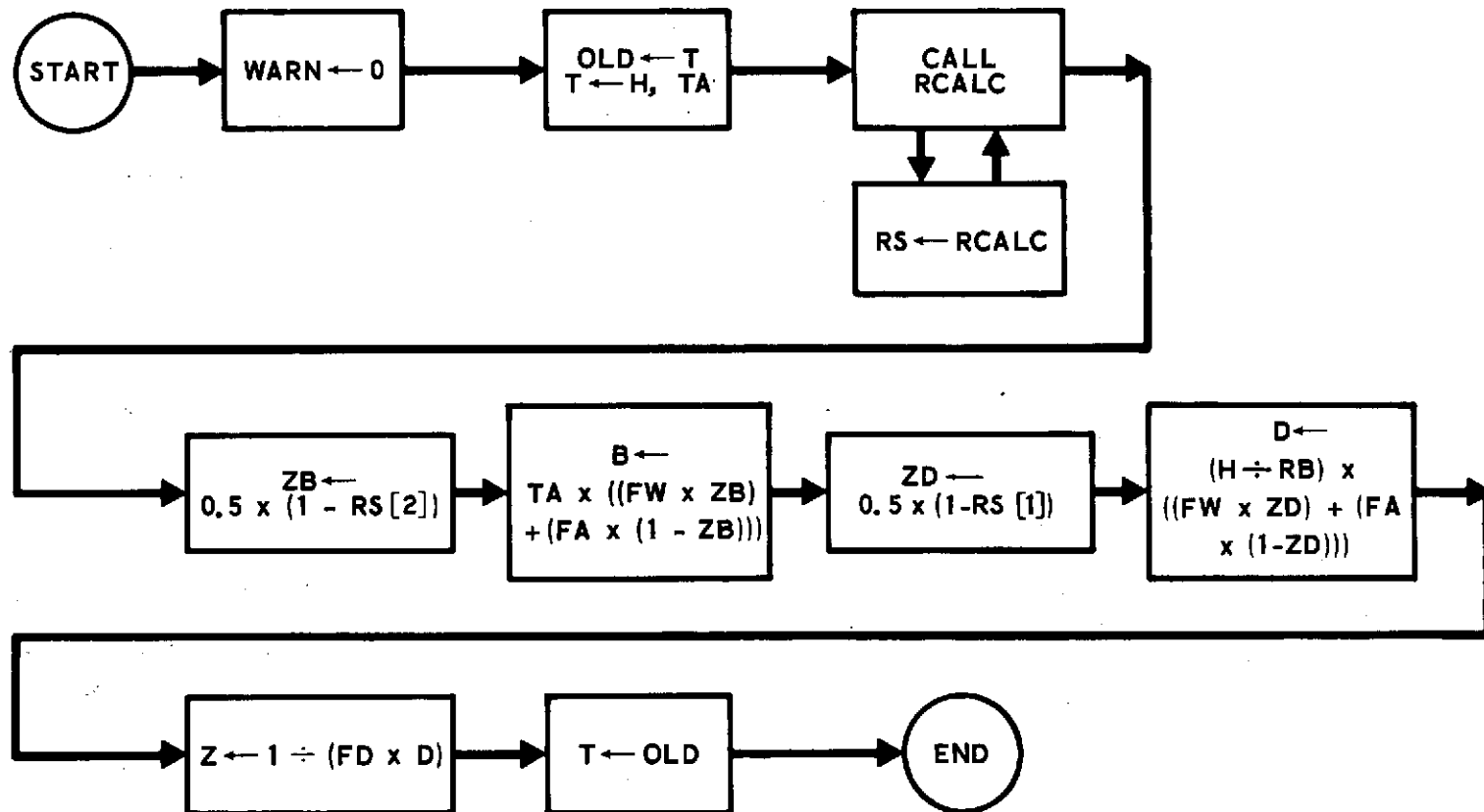


Figure 4-40. ZDZB Flow Chart



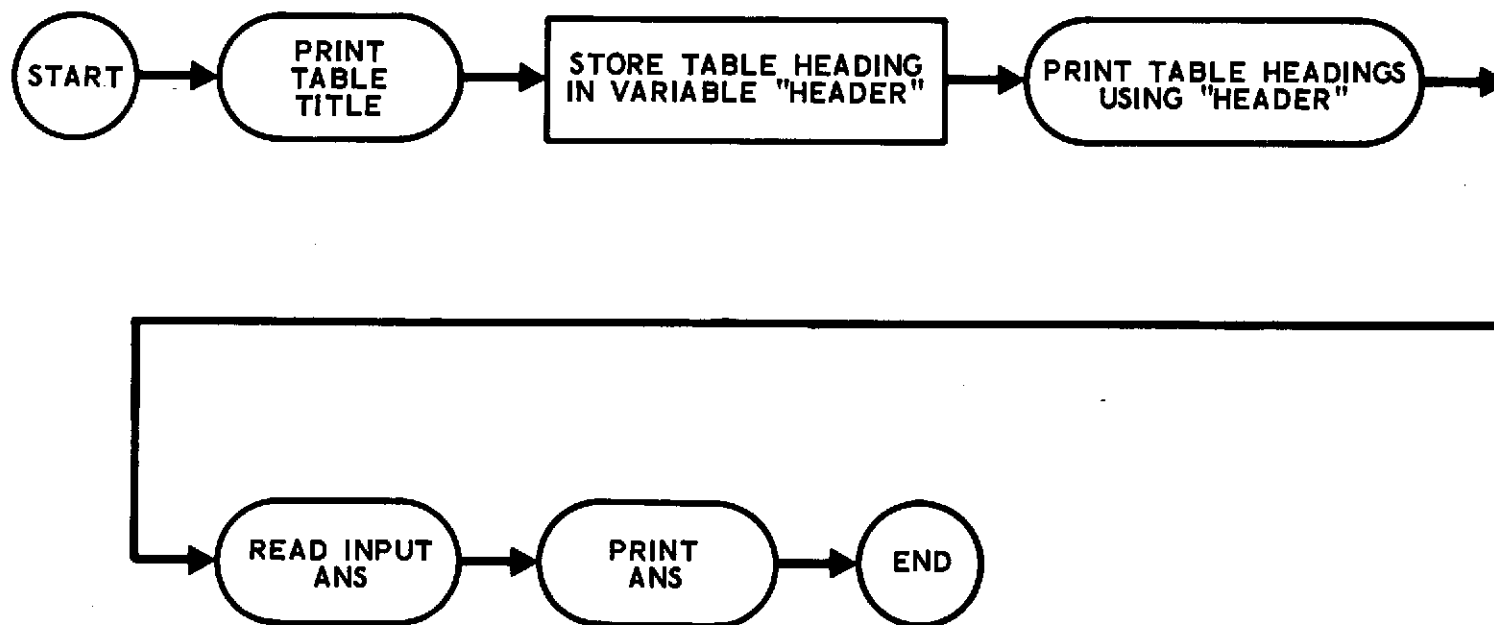


Figure 4-41. AVFORM Flow Chart

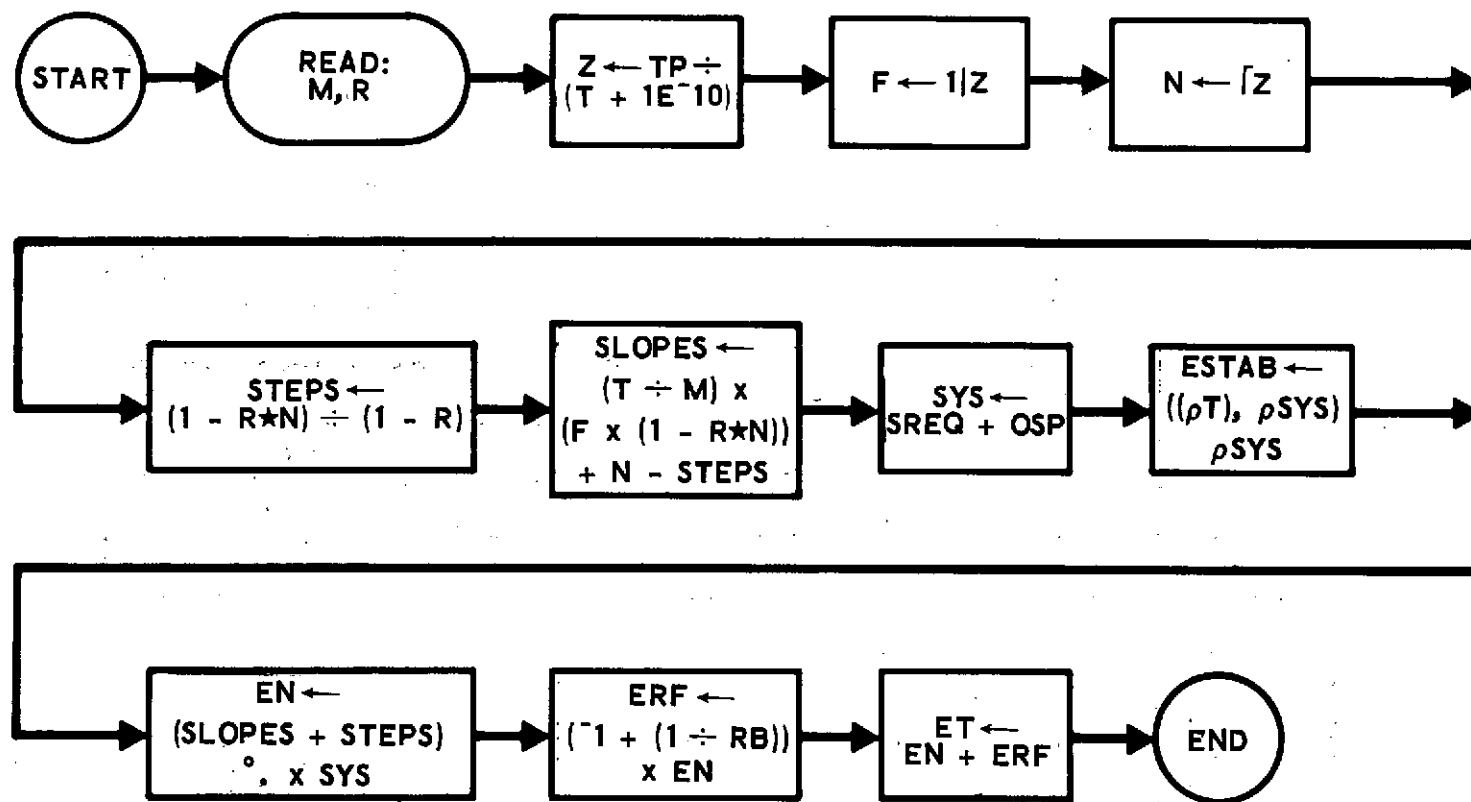


Figure 4-42. ENSTAT2 Flow Chart

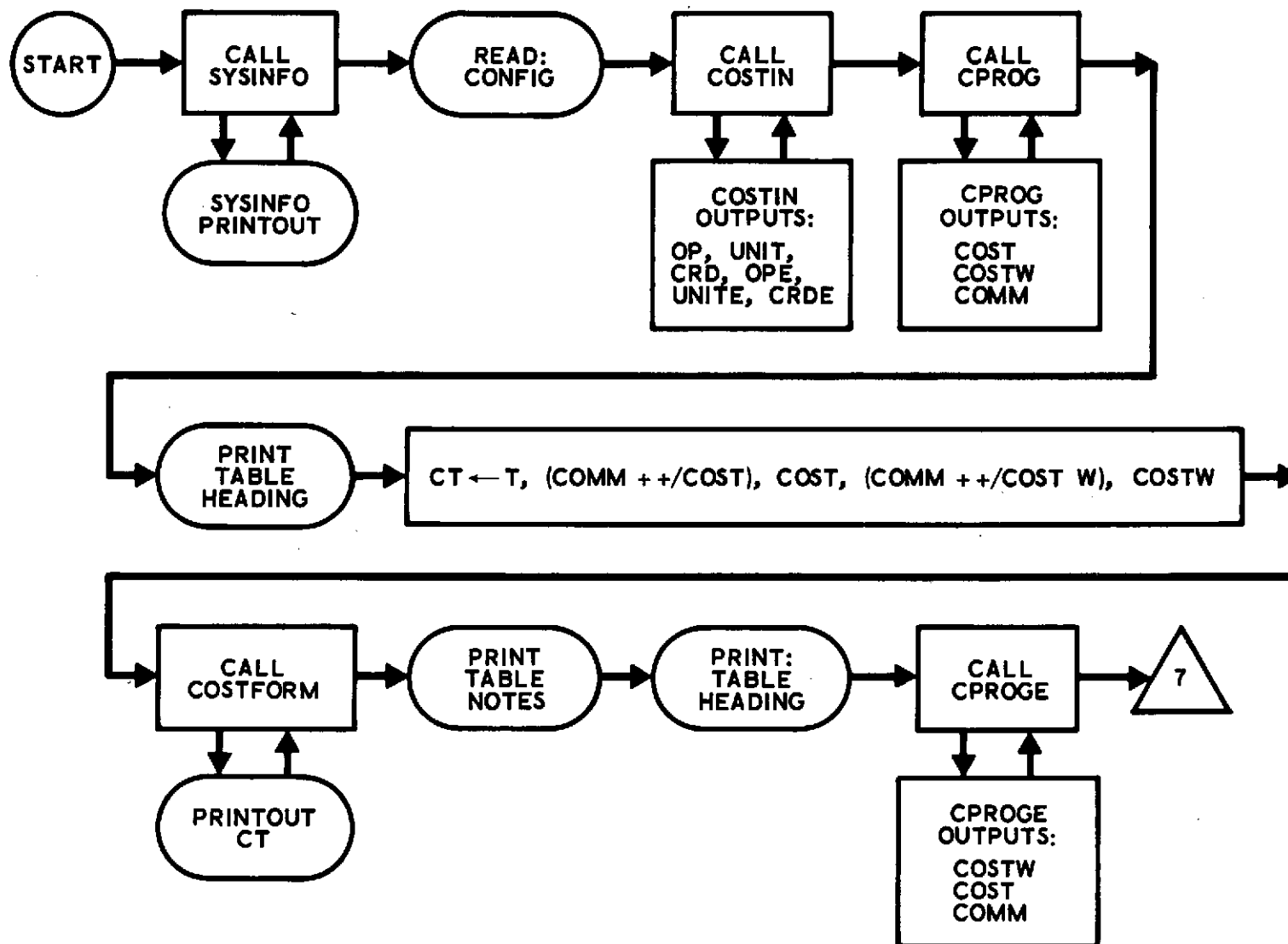


Figure 4-43. CINT Flow Chart

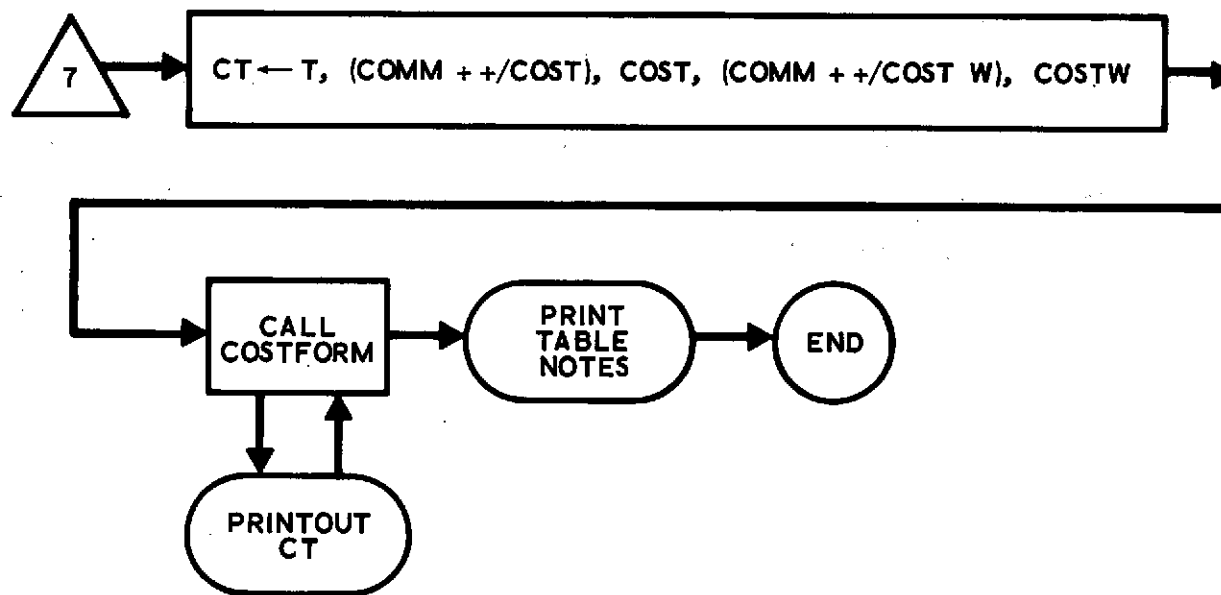


Figure 4-43. CINT Flow Chart (Cont'd)

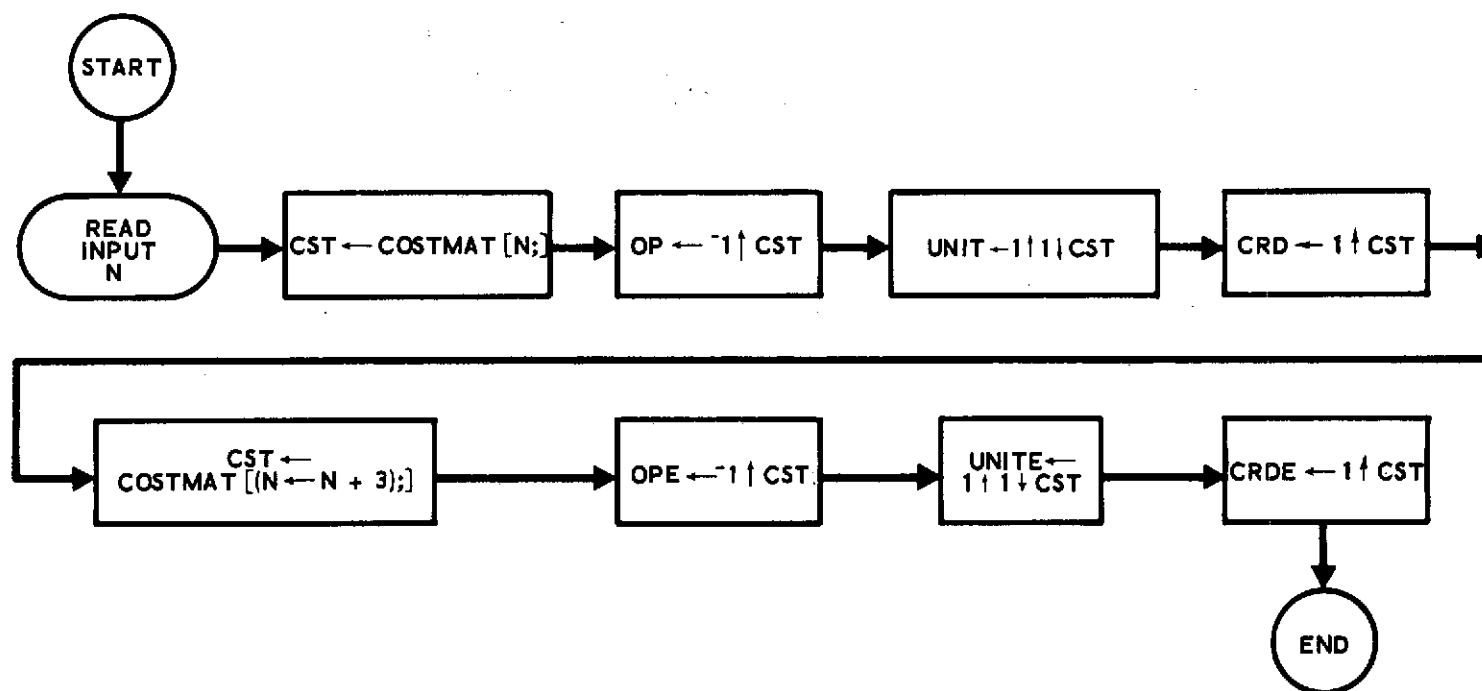


Figure 4-44. COSTIN Flow Chart

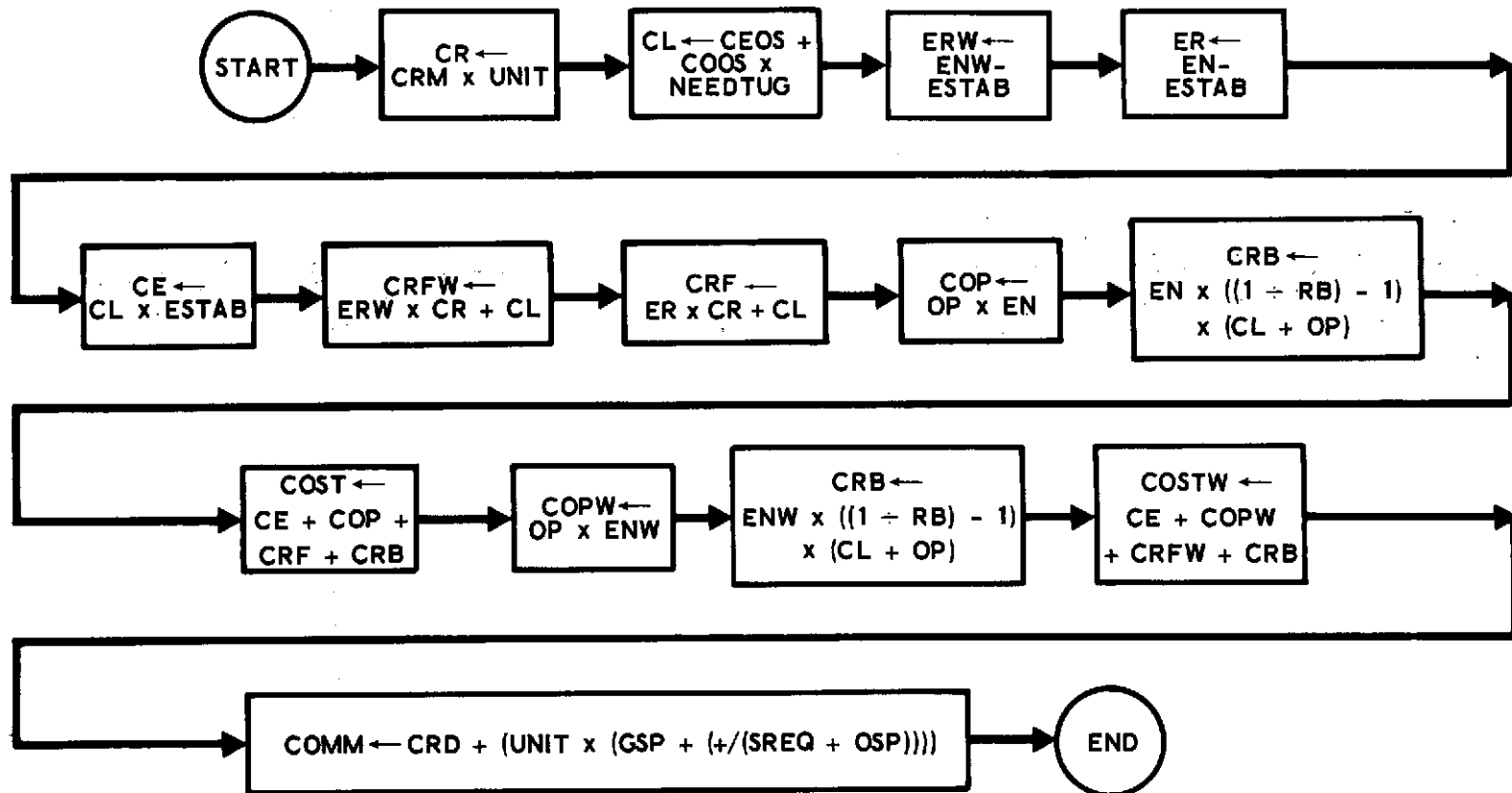


Figure 4-45. CPROG Flow Chart

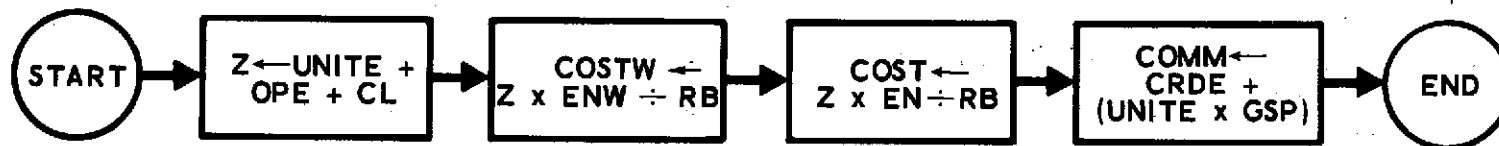


Figure 4-46. CPROGE Flow Chart

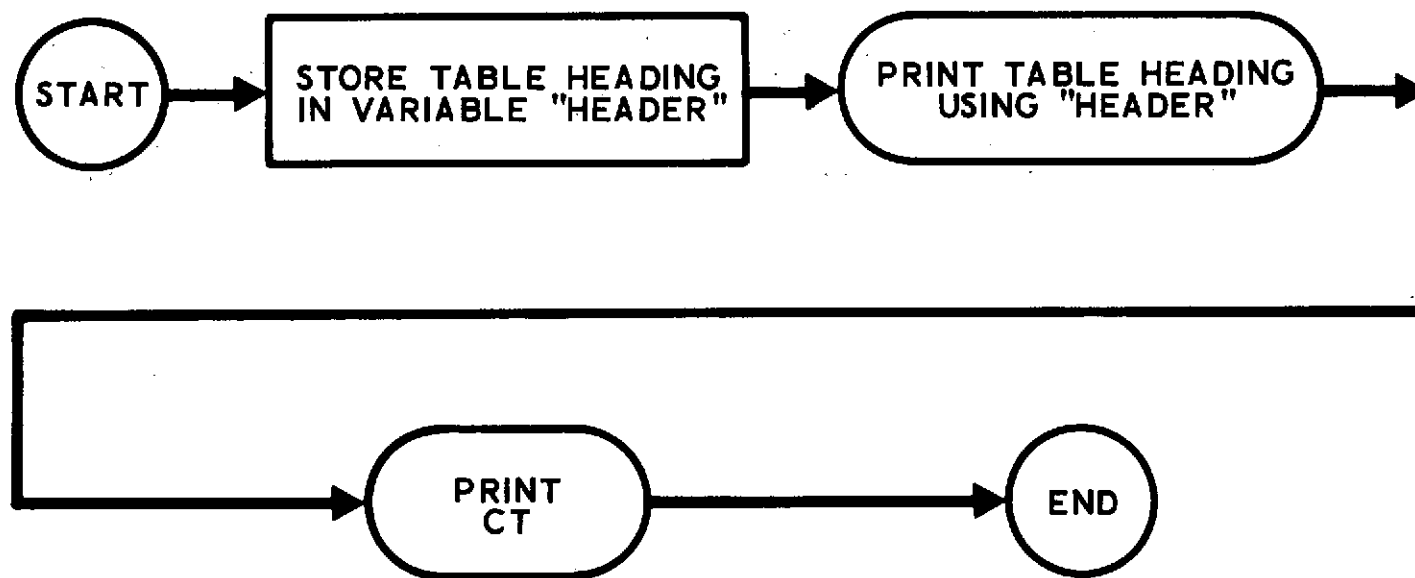


Figure 4-47. COSTFORM Flow Chart



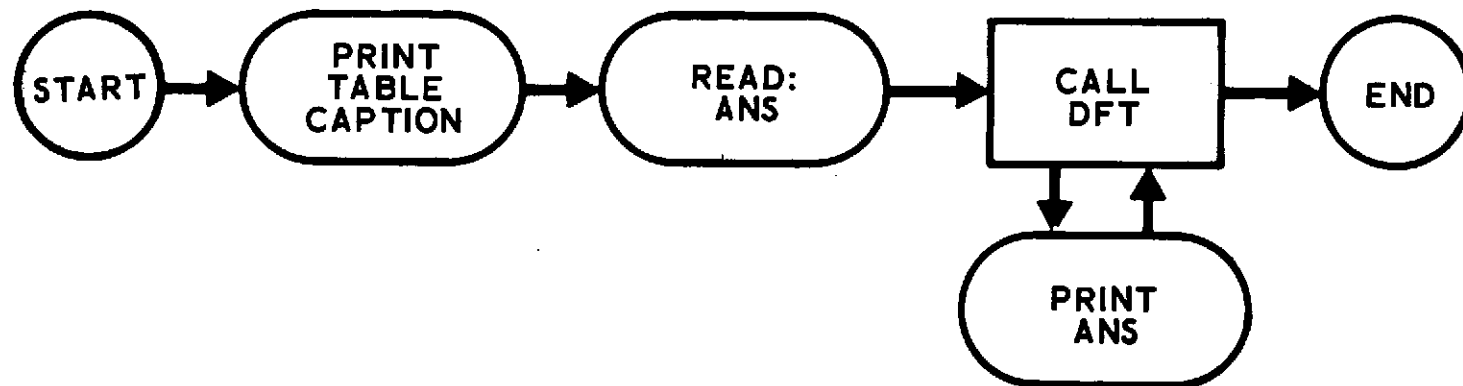


Figure 4-48. ENFORM Flow Chart

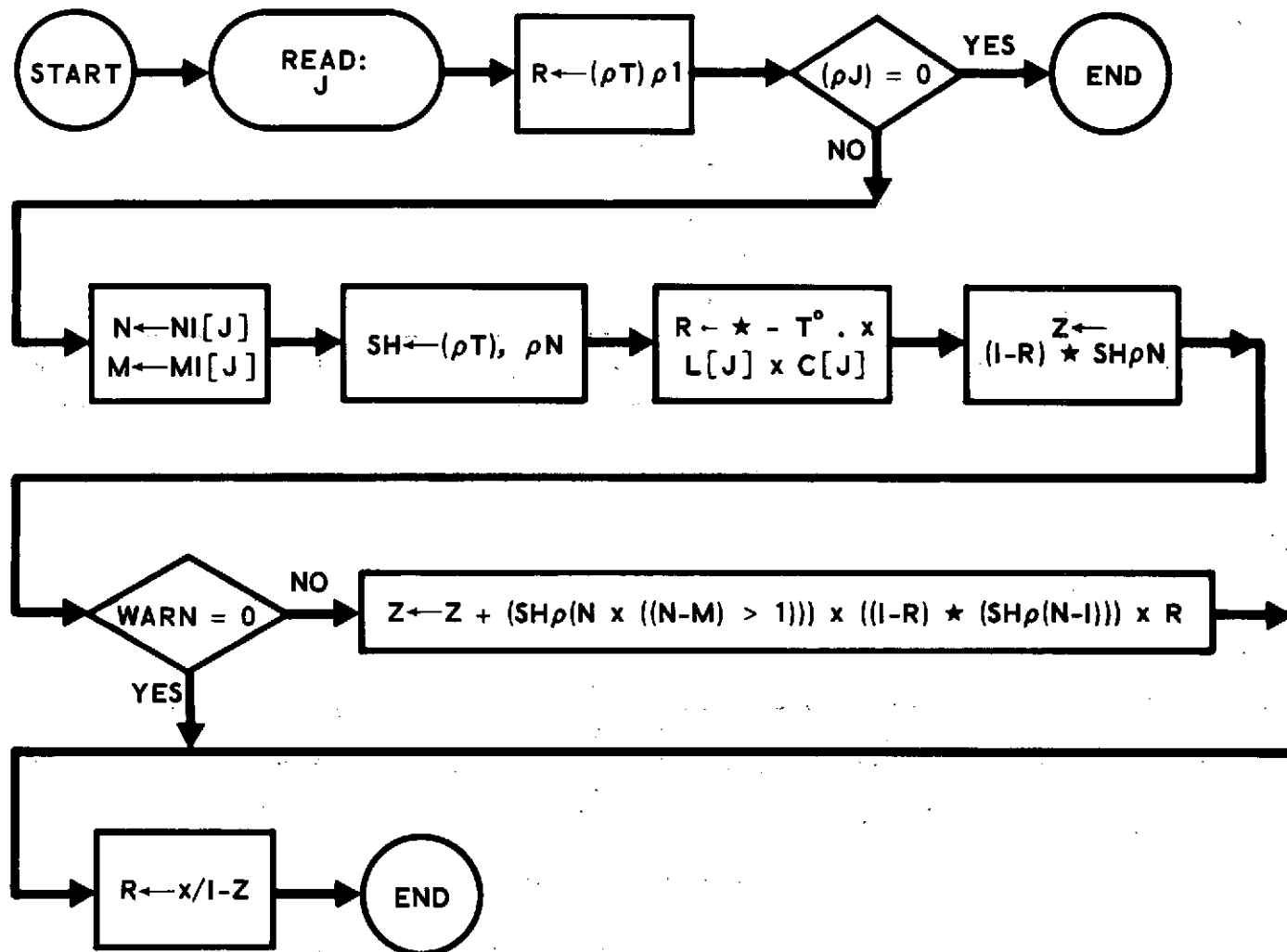


Figure 4-49. ACT Flow Chart

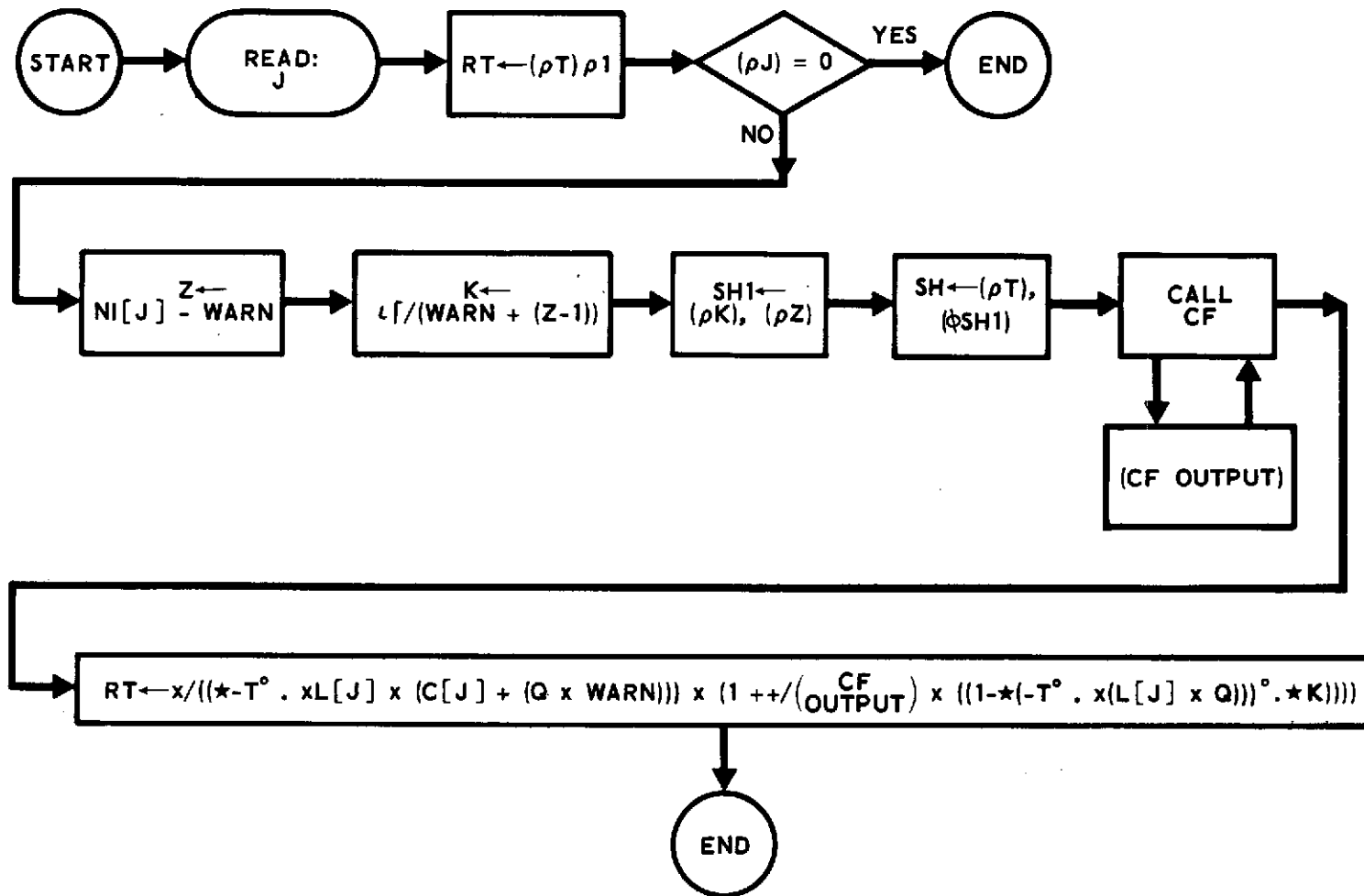


Figure 4-50. STDBY Flow Chart

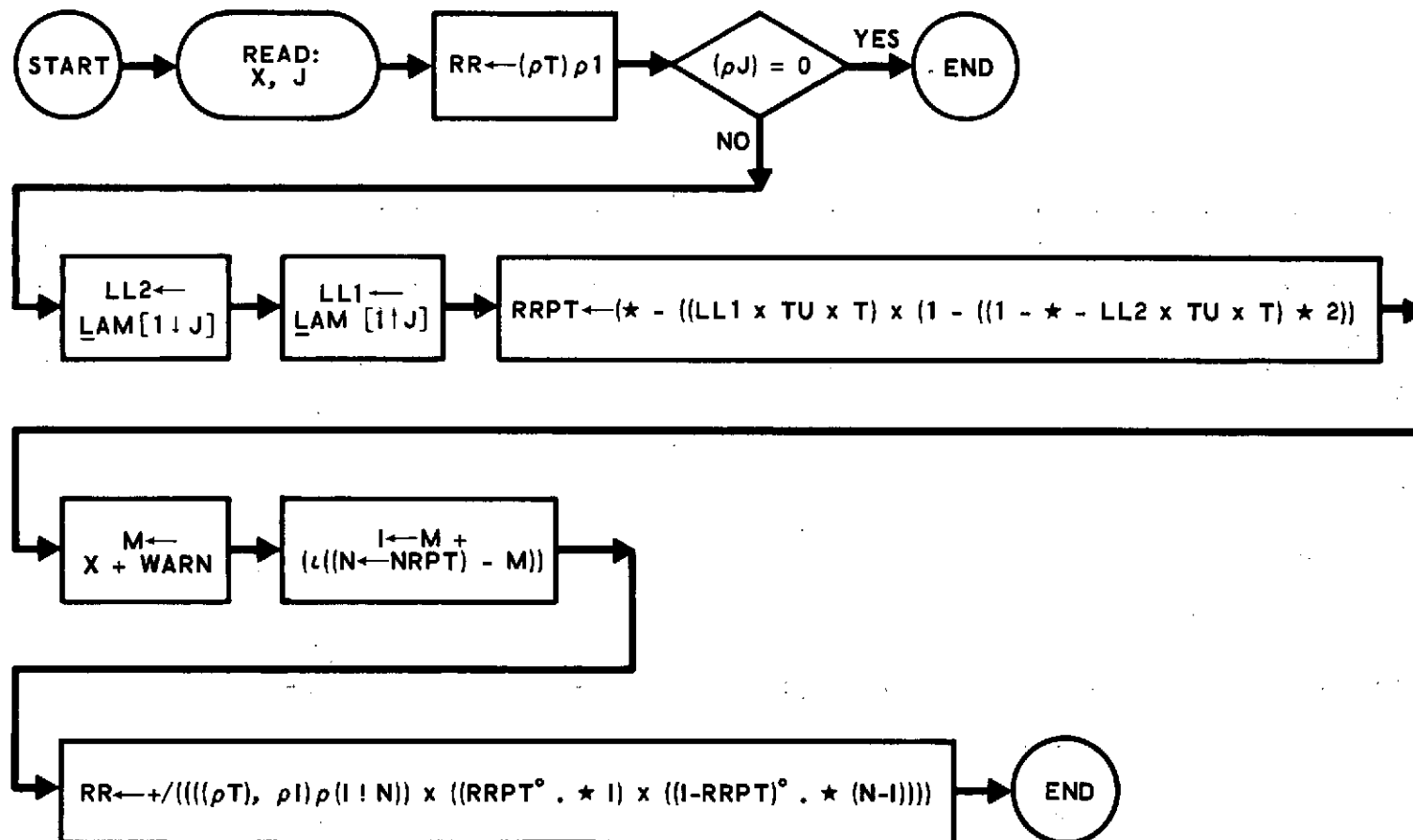


Figure 4-51. RPTR Flow Chart

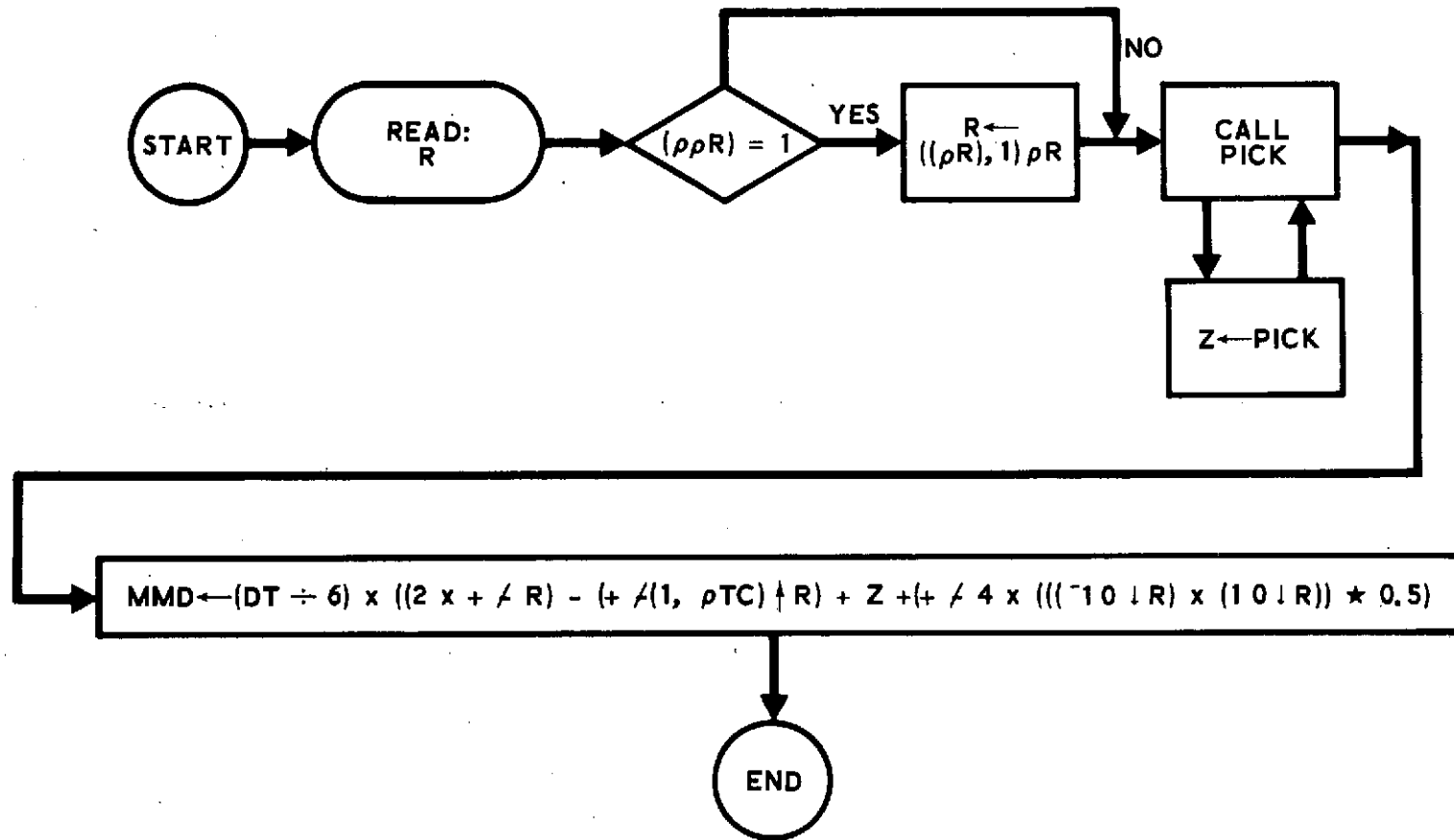


Figure 4-52. SIMPMAT Flow Chart

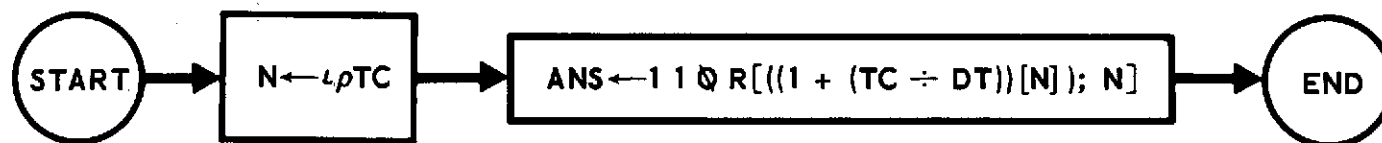


Figure 4-53. PICK Flow Chart

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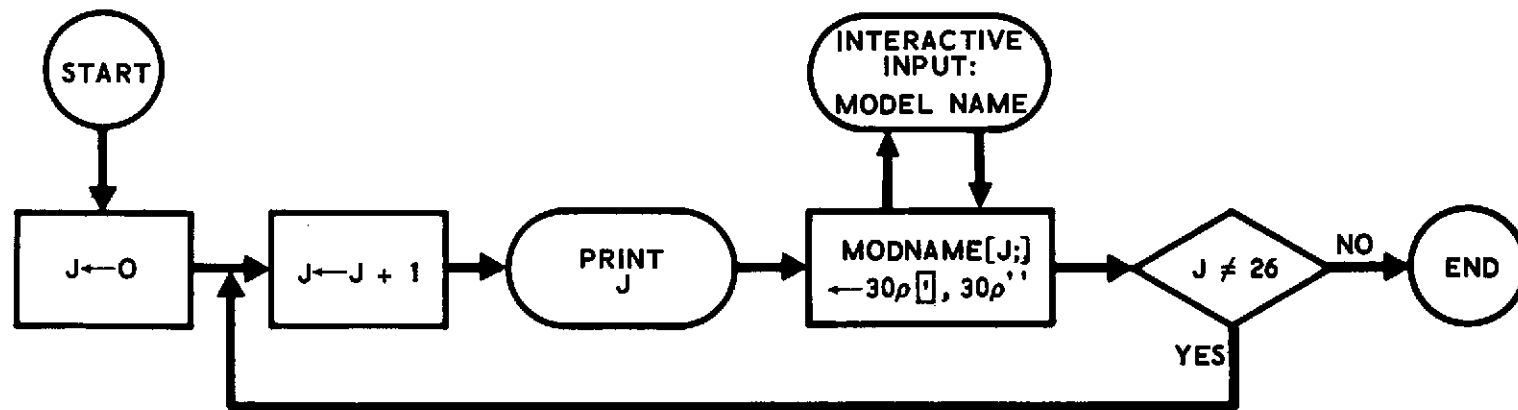


Figure 4-54. MODULES Flow Chart

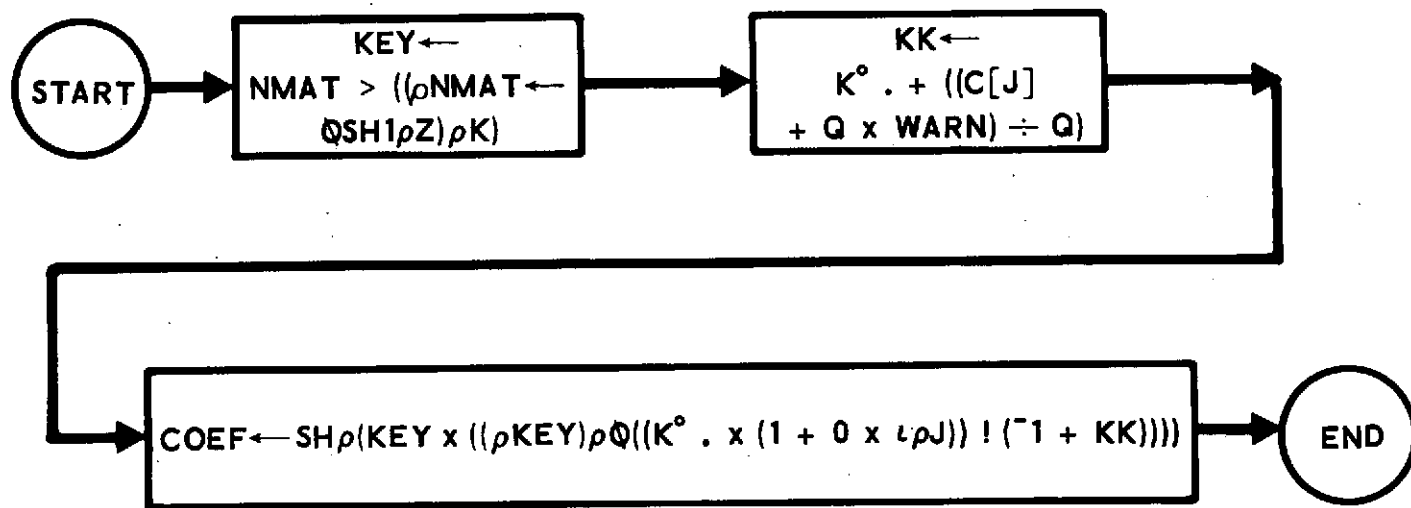


Figure 4-55. CF Flow Chart



the analyst. This is, admittedly, an oversight which will be corrected in due time. This section will describe the data needed to define the satellite (Intelsat), system, and launch vehicle inputs. A printout of the step-by-step keyboard session used to define and store all the input data and to save the global variables is provided. The required data are:

(1) System Data

GSP	A scalar. # of ground spare satellites
SREQ	A vector. # of satellites required/zone for success
OSP	A vector. # of orbital spare satellites/zone
TP	A scalar. Program length (months)
TV	A scalar. # of hours in time unit (1 mo = 730 hrs)
DT	A scalar. # of months per interval of time in line of the printout
HVEC	A vector of launch delays for printout
TAVEC	A vector of spare activate times for printout.

(2) Satellite Data

NMAT	A matrix of $N_i$ for three configurations
<u>L</u> AM	A vector of $\lambda_i$ for the various modules (the failure rate, in failures per hour, of the "black boxes"
DUTY	A vector of duty cycles for the various modules
MI	A vector of the number of "black boxes" required for mission success for the various modules
RMOD	A vector identifying the redundancy types (eqns) for the various modules
	(a) Active
	(b) Standby
	(c) Repeater (special)

Q	A scalar.	Ratio of $\lambda_{\text{off}}/\lambda_{\text{on}}$ (0.5 for hi-rel parts)	
X	A scalar.	Service level for repeaters	
NRPT	A scalar.	# of repeaters in satellite	
$\underline{L}L1$	A scalar.	$\lambda_{\text{RPT}}(\text{serial}) = \underline{L} \text{ AM } [3]$	
$\underline{L}L2$	A scalar.	$\lambda_{\text{RPT}}(\text{redund.}) = \underline{L} \text{ AM } [4]$	
RINF	A scalar.	Prob. of surviving "infant mortality" period.	
COSTMAT	A matrix of satellite costs for each of three configurations, reusable and expendable P/L modes		
	CRD1 <sub>R</sub>	UNIT1 <sub>R</sub>	OP1 <sub>R</sub>
	CRD2 <sub>R</sub>	UNIT2 <sub>R</sub>	OP2 <sub>R</sub>
	CRD3 <sub>R</sub>	UNIT3 <sub>R</sub>	OP3 <sub>R</sub>
	CRD1 <sub>E</sub>	UNIT1 <sub>E</sub>	OP1 <sub>E</sub>
	CRD2 <sub>E</sub>	UNIT2 <sub>E</sub>	OP2 <sub>E</sub>
	CRD3 <sub>E</sub>	UNIT3 <sub>E</sub>	OP3 <sub>E</sub>

(3) Launch Vehicle Data

REOS	Mission Success Probability for Shuttle
ROOS	Mission Success Probability for Tug
CEOS	Lift Cost of Shuttle
COOS	Lift Cost of Tug

The keyboard session (from the APL terminal) is described in Table 4-20.

Table 4-20. Keyboard Session (From APL Terminal)

```

)344300
031) 15.45.44 12/06/73 DAWSON

  A P L \ 3 6 0

)LOAD RISK2
SAVED 14.16.02 11/05/73
  CSP+2
  SREF+2 1 1
  OSP+1 1 1
  TP+144
  TU+730
  DT+12
  HVFC+1E-15 0.5 1 1.5 2
  TAVFC+0 2 4 6 8
  V1+1 4 12 12 2 1 1 2 1 2 2 2 2 2 1 2 2 1 1 1 3 1 1 1 3
  V2+1 6 12 12 2 3 1 3 1 3 4 4 4 6 4 1 3 3 1 2 3 2 1 2 3 2
  V3+1 6 12 12 3 3 1 3 1 3 4 4 4 6 4 1 3 3 1 3 3 3 1 3 3 3
  NMAT+QV1,V2,[1.5]V3
)ERASE V1 V2 V3
  LAN+1E-9*10 6000 500 4000 500 500 10 3750 10 1200 2000 2000 2900 5300 1500 500 200 200 200 100 500 50 200 100 500 50
  DUTY+MI+1+0*126
  MI[3 4]+9
  Q+.5*PD+1
  RMOD+1 1 3 3 1 2 1 1 1 1 1 1 1 1 1 1 1 2 2 2 1 2 2 2 1
  X+8
  NRPT+12
  RINF+.94
  YES+1+NO+0
  COSTMAT+6 3p36.3 9.9 0.9 38.9 11.6 1 39.9 12 1 44 9.5 0.9 48.3 11.2 1 0 0 0
  REOS+.995
  ROOS+.97
  CEOS+.9.8
  COOS+.89
)SAVE
15.16.37 12/06/73 RISK2
)OFF
031 16.16.48 12/06/73 DAW
CONNECTED 0.31.04 TO DATE 1.18.35
CPU TIME 0.00.01 TO DATE 0.00.03

```

d. Sample Optimization and Selection Analysis

The objective of this analysis is to select the lowest cost satellite system approach from the options available. The system selected must meet the availability requirement to obtain comparable risk to the ground system. The flight rate is determined for each of the options as it is analyzed so that when the lowest cost option is selected the flight rate is also selected.

The procedures are developed to provide closed-form solutions for system availability and to derive the associated costs and flight rate. The utility of the computed data in the analysis is in the tradeoff and sensitivity display for the optimization and selection analysis. This section of the report gives the user guidance in the selection procedure by use of an example.

For a general description of the functional aspect of the analysis the reader is referred to Section 2.B.6 of this document. The actual steps that the user goes through in order to accomplish this analysis are:

1. Obtain input data from previous BRAVO steps
2. Follow the computing procedures described in Sections 4.F.2(a), (b) - and 4.F.2(c) if needed
3. Analyze the tabulated results from the computer runs to complete the selection analysis. This is normally accomplished by plotting the data as described in the following example.

Before getting into the example itself, some understanding of the case being illustrated is helpful. The example analysis is for an Intelsat case originally accomplished and described in Study 2.1<sup>(1)</sup>.

---

(1) Space Shuttle Mission and Payload Capture Analysis (Study 2.1)  
Final Report, Volume II, The Aerospace Corporation, ATR-73  
(7311)-I, Vol. II, (15 June 1973)

The APL computer program, RISK, was used to simulate each of the cases from Study 2.1 plus one additional satellite option, a 3-axis, stabilized satellite designed according to LMSC low-cost principles. The calculated outputs are on file at The Aerospace Corporation. Thus the options analyzed from which a selection of the lowest cost is to be made are:

1. A dual-spin satellite with the Intelsat IV configuration as it was built and flown. This is a dual-spin satellite and carries the label "CDR dual-spin (as built)." Design life of this satellite is seven years limited by wearout.
2. A dual-spin Intelsat IV design resembling the as-built satellite but with redundancy increased on a weight-optimized basis. The redundancy increase has two effects; first the reliability curve of the satellite is improved, second the number of redundant components for which failures could be tolerated before a launch-on-warning is increased. Design life of this satellite is seven years limited by wearout. This satellite option is labeled CDR (weight-optimized dual-spin).
3. A 3-axis satellite design carrying the Intelsat IV mission equipment (transponders, antennas, and supporting communications). This satellite has a five-year design life. It is designed according to the LMSC low-cost design principles; it is fully modularized and can be maintained on orbit or on the ground. This option is labeled LCR (3-axis).

Each of the options was analyzed in two orbital deployment configurations. The first is a four-satellite system with one over the Pacific, one over the Indian, and two over the Atlantic oceans. For this system there are no spare satellites in orbit, only two on the ground. The second on-orbit deployed configuration is a seven-satellite system with one active spare added over each ocean area. All failed satellites are repaired on the ground.

For the CDR satellite design options, each orbital deployment configuration is analyzed for launch-on-warning and launch-on-failure strategy satellite replacement. The analysis simulates logistics for

replacement of failed or failing satellites and repair or refurbishment on the ground. The analyses in Study 2.1 have shown that periodic preventative maintenance at intervals less than seven years (the satellite wearout time) was more expensive; therefore, this analysis used seven-year preventative maintenance intervals. For the purpose of obtaining program costs, a twelve-year Intelsat program duration was assumed.

(1) Discussion of Detailed Steps and the Optimization and Selection Procedure

Once the computer program (RISK) has been used, the system optimization (against satellite design and logistics options) data are available in tabulated form from the RISK computer program printout. These results are then analyzed by making appropriate graphs and plots which illustrate the relative costs and risks of the various options analyzed so that conclusive observations may be made from the data by the user. The availability requirement for the example (Intelsat) system is 0.9999.

Step 1 - Plot Data

Step 1 is for the user to plot the data according to the example format to provide rapid comparison and analysis with visibility into the system tradeoffs. The bar graph (Figure 4-56) displays the relative costs of the various options analyzed at normal operating conditions. In this case normal conditions are a two-month delay for satellite replacement, no satellite turn-on delay, and a failure rate multiplier ( $\lambda$  factor) of 1.0. Figure 4-57 displays the effects on availability of perturbing the launch delay in replacing the failed satellite. Satellite replacement delay is primarily a matter of the availability of the launch vehicle for a replacement mission on short notice. It is assumed that the cost differences between less than one month delay and up to four months delay is negligible.

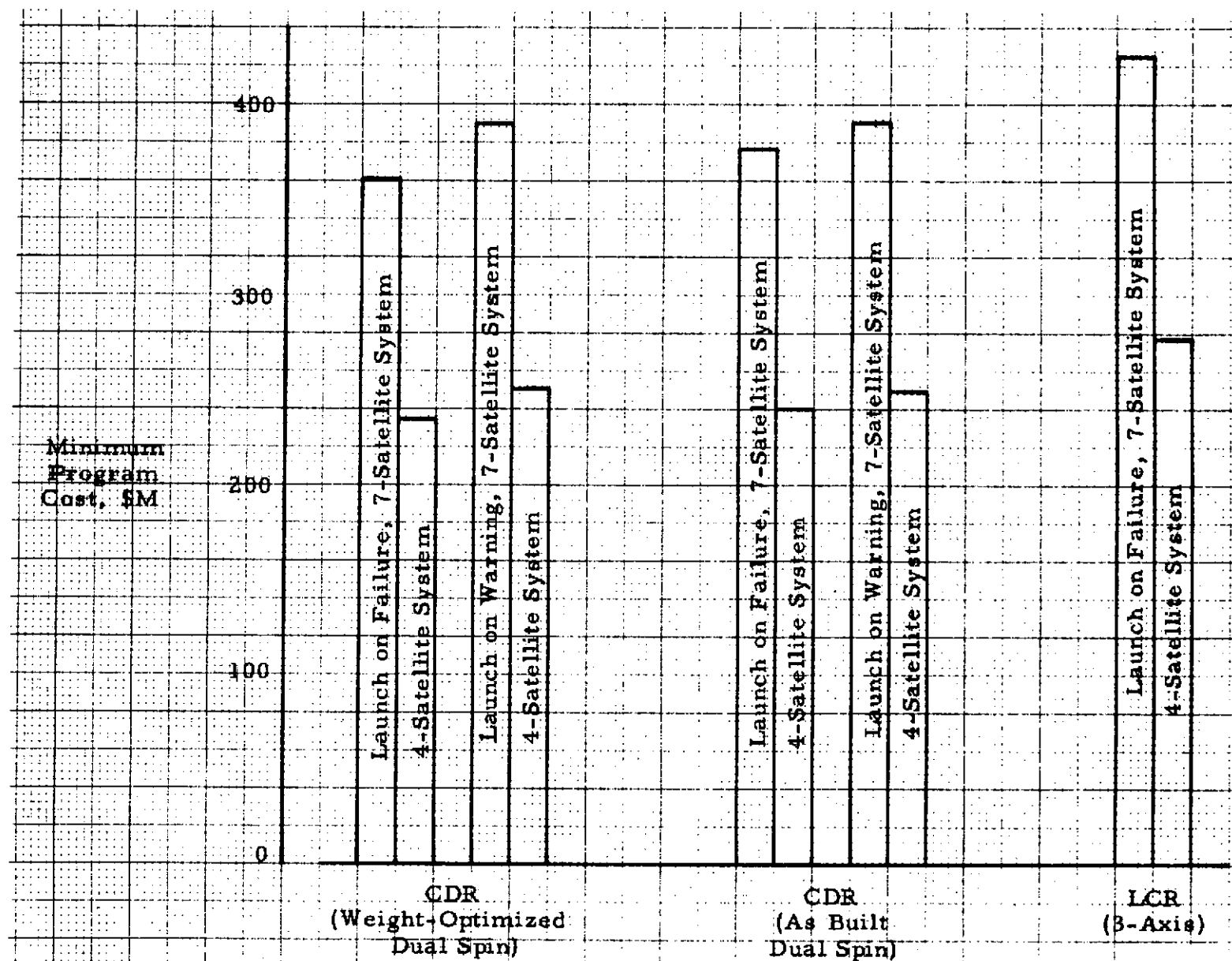


Figure 4-56. Minimum Program Cost Comparison, 12-Year Program, 1972 Dollars, Intelsat IV Example, 7-Satellite System,  $\lambda$  Factor = 1.0

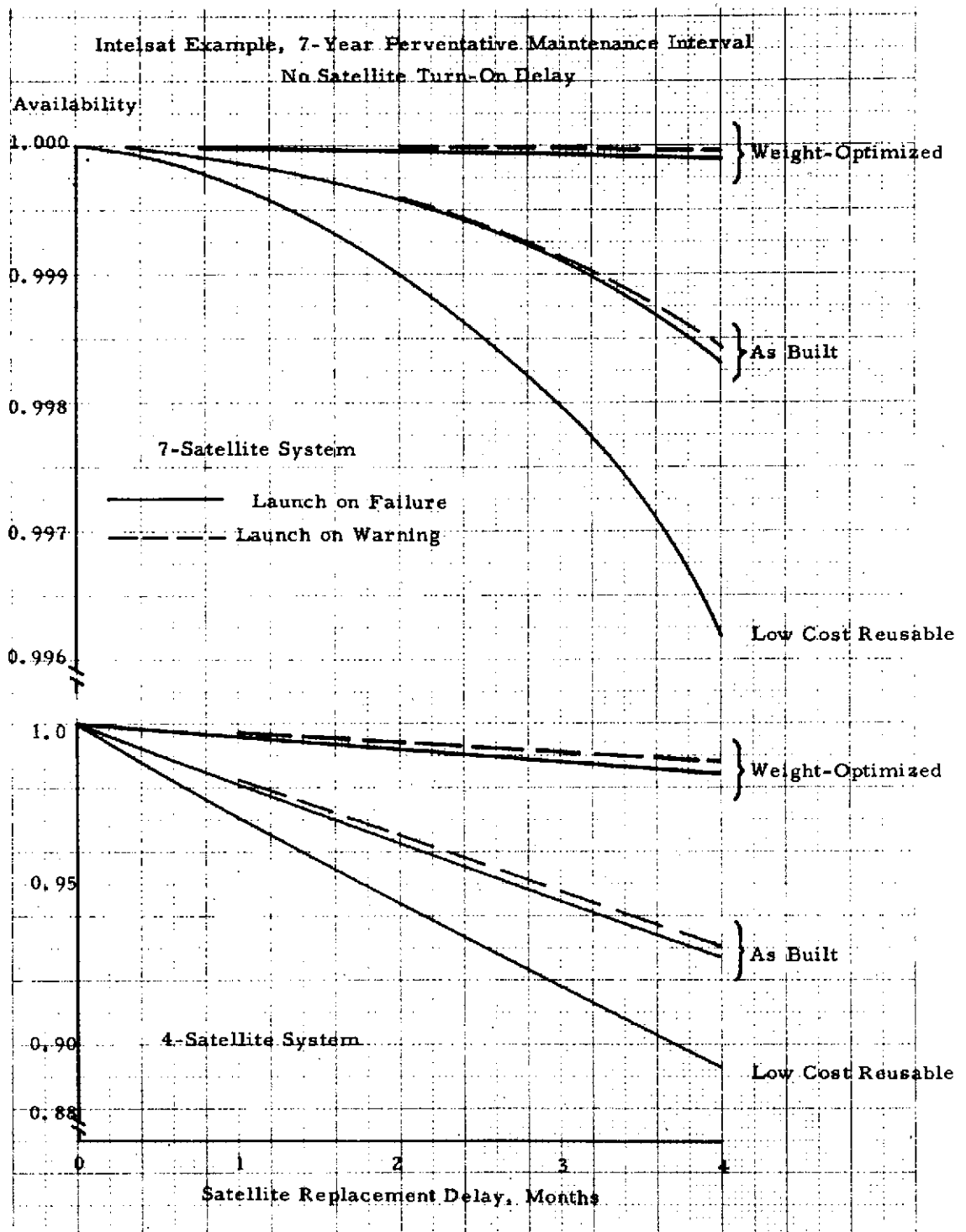


Figure 4-57. Effect of Launch Delay on System Risk



Figures 4-58 and 4-59 display the effects of satellite failure rate multiplier (or  $\lambda$  factor) on system availability and program cost. A failure rate multiplier of 1.0 indicates that the satellite performance matched the design reliability curve. A failure rate multiplier of 1.5 indicates that the satellite failure rates increased 50 percent over the design values in actual operation. These data are primarily useful in checking the sensitivity of system parameters to failure rate.

### Step 2 - General Observations

The user makes general observations on satellite costs for candidate systems for the purpose of eliminating as many candidates as possible. From the plotted data (see Figure 4-56), it is noted that the 3-axis system is more expensive and from Figure 4-57 it is noted that the 3-axis system exhibits lower availability in each case, thus the 3-axis system can be eliminated.

It is noted that the systems with four satellites on orbit (instead of seven) all exhibit outages in excess of the allowable 0.0001 (see Figure 4-57), thus four-satellite on-orbit systems may be eliminated.

Surviving candidates are the seven-satellite system with dual-spin designs. It is noted that the as-built dual-spin design will meet the availability requirement if the satellites can be replaced with delays of three weeks or less (see Figure 4-57). It is also noted that the weight-optimized dual-spin design will meet the availability requirement with up to four months replacement delay for a launch-failure strategy (see Figure 4-57).

It is noted that the spare satellite turn-on delay rapidly lowers availability below the required 0.9999 (see Figure 4-60). It is therefore concluded that spare satellites on orbit for this system should be active spares.

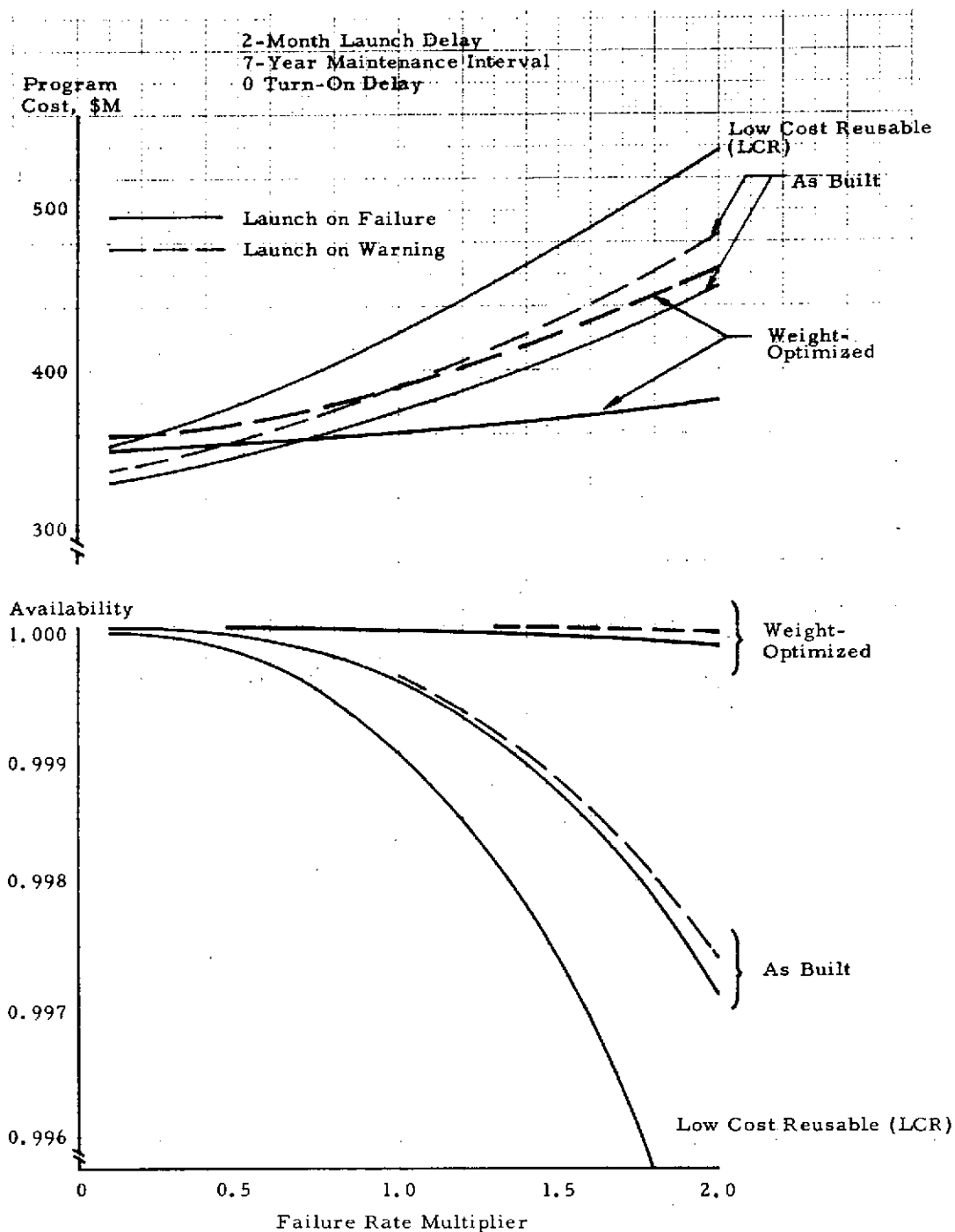


Figure 4-58. Sensitivity of Availability and System Cost to Satellite Failure Rate, Seven-Satellite System

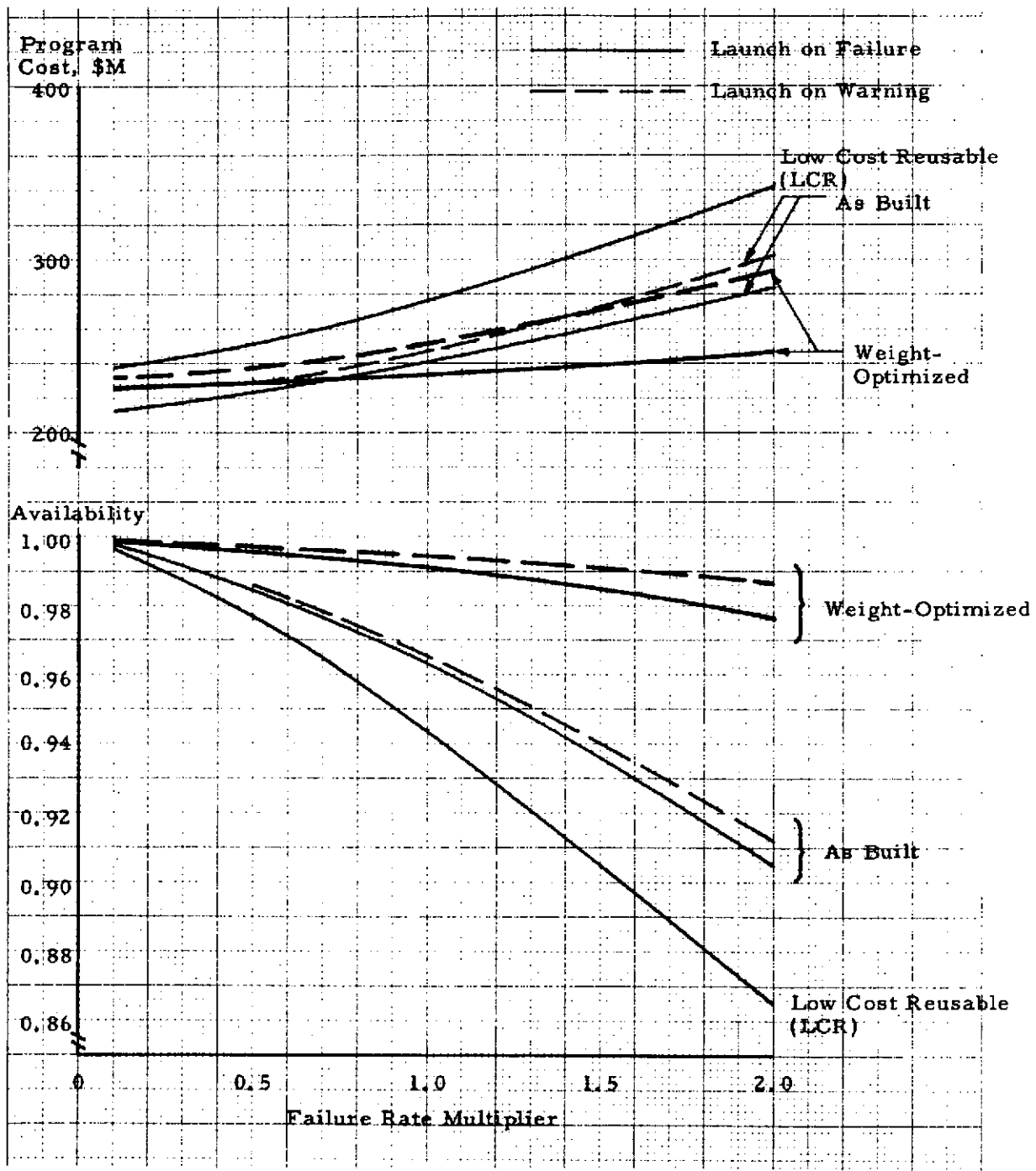


Figure 4-59. Sensitivity of Availability and System Cost to Satellite Failure Rate, Four-Satellite System

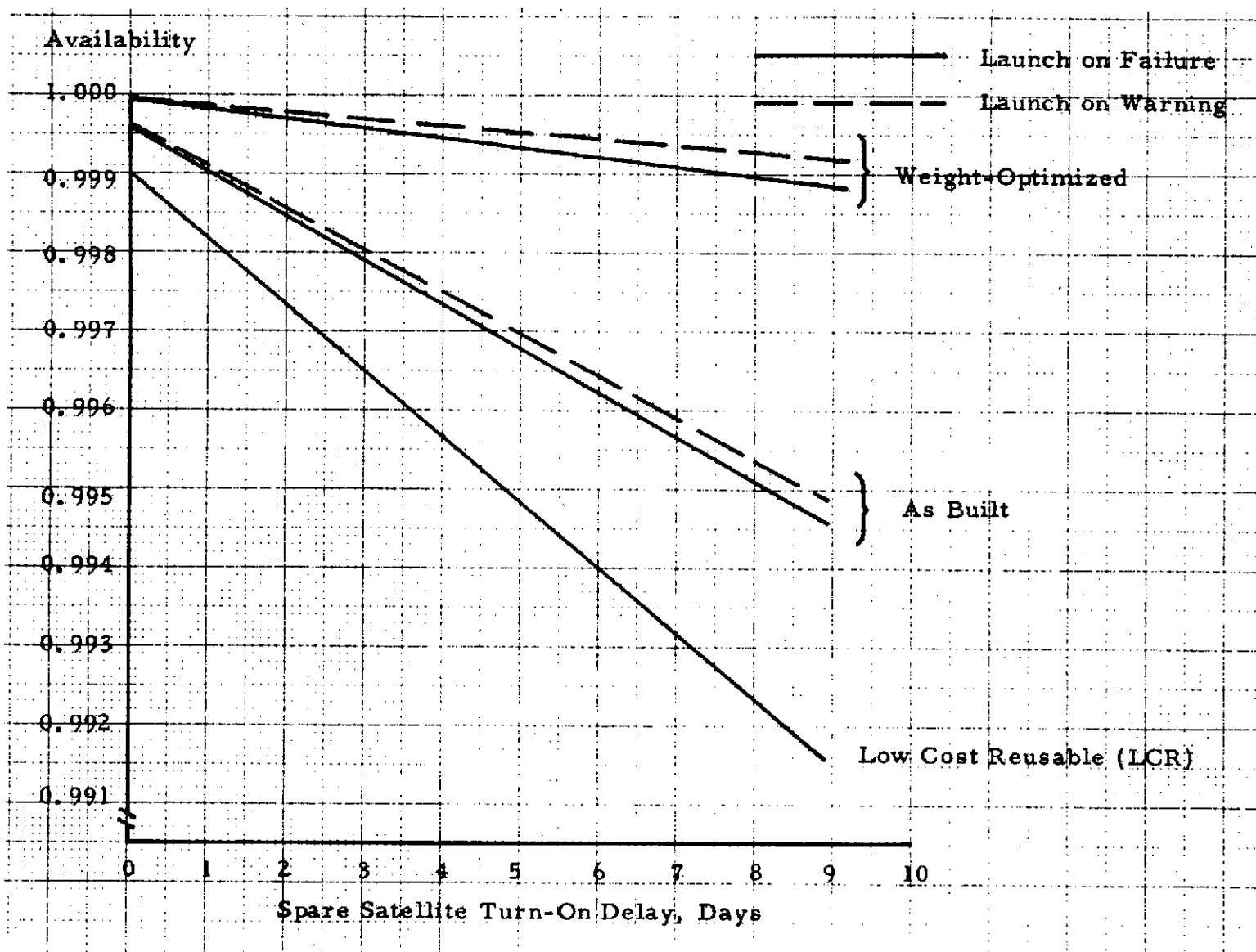


Figure 4-60. Sensitivity of System Availability to Spare Turn-On Delay

### Step 3 - Select Lowest Cost System Meeting Equal Risk Criteria

The remaining options are seven-satellite orbital configurations for both current reusable design (CDR) satellites, the weight-optimized dual-spin version, and the as-built dual-spin version. The weight-optimized dual-spin design is the lowest cost operating with a launch-on-failure logistics strategy (see Figure 4-56), however, the costs for the as-built dual-spin system is close (\$370 million vs \$350 million) and should not be eliminated on the basis of cost only. For example, the lower initial cost could make the CDR as-built dual-spin design more attractive than the CDR weight-optimized dual-spin design.

### Step 4 - Assess Satellite System Risk Sensitivity

Since the costs for the as-built design and weight-optimized design are close, the sensitivities of the risk assumptions become an important consideration. The sensitivity of availability to failure rate is low (see Figure 4-58) for the weight-optimized design compared to the as-built design. For the weight-optimized design an increase in failure rate of 60 percent still exhibits an availability of 0.9999.

In addition, it is noted that the sensitivity of the availability of the weight-optimized design to launch delay (see Figure 4-57) also supports the selection of the weight-optimized dual-spin satellite design as the representative approach for the space system. Launch-on-failure could be the preferred strategy for satellite replacement.

The output of this analysis is (1) the confirmation of the ability of the selected system to meet the availability requirement of 0.9999, thus establishing equal risk with the competitive ground systems, and (2) the selection of the weight-optimized dual-spin satellite with active spares using the launch-on-failure logistics strategy as the lowest cost space system approach. The output of the RISK computer program also shows 17 STS launches required to support the twelve-year program using the selected satellite approach.

Other general observations may be of interest, although they have no bearing on the specific problem illustrated here.

1. At a lower availability requirement (0.999 or lower), the as-built dual-spin satellite design would have to be compared with the weight-optimized dual-spin design on the basis of net present value (see Economics Analysis Section) to determine the best selection.
2. The payoff for launch-on-warning strategy is limited to very high availability requirements and enriched (highly redundant) satellites such as the weight-optimized dual-spin version analyzed here (see Figures 4-58 and 4-59).

## 5. TERRESTRIAL SYSTEMS ANALYSIS

### A. TELECOMMUNICATION SYSTEMS

#### 1. ALTERNATE SYSTEM OPTIONS

The costs of satellite communication systems may be compared with the costs of terrestrial communications systems of three types: (1) common carrier telephone systems (e.g., ITT, ATT, GT, etc.), and (2) dedicated systems constructed to perform a specific mission or furnish specialized carrier system leased services (e.g., Microwave Communications, Inc. or DATRAN).

The character of the mission requirements will determine the most economical terrestrial system approach. In general, the communication requirements between terminals in population centers in all but "emerging" nations can be satisfied by common carrier telephone networks.

Under some circumstances, specialized carriers may provide more economical service than common carriers owing to their design to perform specialized service (e.g., narrow and wide band data with fast switching to accommodate short message length) between pairs of population centers with large demand for the service. However, such systems do not serve remote, light-traffic areas.

Dedicated systems may be required where the mission requires capacity too large to be provided by parts of the existing common carrier network, as, for example, in sparsely populated areas or "emerging" nations.

#### 2. SYSTEM SELECTION

To define an appropriate terrestrial system, the following five steps should be taken:

- (1) Define communication requirements to provide the same service for comparison, as the satellite system. Specify communication traffic peak load requirements for all links, year-by-year, in terms of number of voice circuits required and number and bit rate of data channels.
- (2) State country in which each communication terminal is located.
- (3) Calculate distances of links between pairs of terminals and specify whether each is U. S. domestic, foreign domestic, foreign international, or trans-oceanic (e. g., for use in Table 5-1).
- (4) Calculate costs for each option (common carrier, leased circuits, and dedicated systems and compare cost streams).
- (5) Specify whether each link is to be leased, common carrier, or constructed as a dedicated link on the basis of lowest cost.

### 3. ESTIMATING COSTS OF LEASING FROM COMMON CARRIERS

For leased circuits, calculate costs as follows:

- (1) Calculate voice circuit costs using the worksheet, Table 5-1<sup>(1)</sup>.
- (2) Calculate data transmission channel<sup>(2)</sup> costs using the worksheet, Table 5-2<sup>(1)</sup>.
- (3) Calculate total annual costs for each year using the worksheet, Table 5-3.

Total annual costs for all links, as calculated above for each year, are the annual costs for the leased terrestrial system for input to the economic analysis. These costs are all annual operating costs where the system is entirely leased (no purchased equipment).

- 
- (1) Terminal costs should be excluded for comparison with satellite systems costs.
  - (2) A circuit is two (one-way each) channels. Charges for one-way and two-way data transmission are the same. Two-way (duplex) voice circuits cost 10 percent more than one-way (simplex) voice channels.



Table 5-1. Worksheet, Leased Voice Circuit Costs by Year, 1973 Dollars

Link Identification <sup>(1)</sup>						
Location <sup>(2)</sup>						
Distance (km)						
Cost/Year/Circuit, 1973 <sup>(3)</sup>						
Annual Costs:						

Year	Trend Factor <sup>(4)</sup>	# Ckts/ Cost <sup>(5)</sup>	# Ckts/ Cost	# Ckts/ Cost	# Ckts/ Cost	# Ckts/ Cost	Total Cost

- (1) Any convenient designation, such as names of terminals.
- (2) U.S. domestic, foreign international, foreign interexchange, or transoceanic.
- (3) From Figure 5-1 or Figure 5-2, depending on location. Add \$1600 for circuit terminal costs if appropriate for comparison with other systems.
- (4) Table 5-4.
- (5) Enter number of circuits in the link in the upper left corner of each box and the cost in the lower right corner. Annual cost equals (cost/year/circuit, 1973) x (trend factor) x [(number of circuits)<sup>0.72</sup>].

Table 5-2. Worksheet, Leased Data Transmission Channels by Year, 1973 Dollars

1. Link Identification <sup>(1)</sup>							
2. Location <sup>(2)</sup>							
3. Data Rate (kbps)							
4. Distance (km)							
5. Cost/Yr/km @ 1609 km, Fig. 5-3							
6. Distance Factor Fig 5-4							
7. Comm. Line Cost (4x5x6)							
8. Terminal Cost <sup>(3)</sup> Fig. 5-5							
9. Line & Term. Cost (7+8)							
10. Location Factor <sup>(4)</sup>							
Annual Cost <sup>(5)</sup>							Total Cost
Year	Trend Factor Table 5-4						

- (1) Any convenient designation, such as names of terminals.
- (2) Location: U.S. domestic, U.S. transoceanic, foreign interexchange, or foreign international.
- (3) One set of terminal equipment is required at each end of a link. Include if terminal costs are included for systems with which this system is compared.
- (4) U.S. domestic factor = 1.0; U.S. transoceanic factor = 3.0; foreign interchange factor = 1.8; foreign international factor = 2.9.
- (5) Annual cost = (line 7) x (line 10) x (trend factor), or Annual cost = (line 9) x (line 10) x (trend factor) if terminal costs are included.

Table 5-3. Worksheet, Leased Communications Costs  
Summary

		Annual Costs, 1973 Dollars									
Year →											
Voice Circuit Costs (From Table 5-1)											
Data Chan. Costs (From Table 5-2)											
Total Lease Costs											

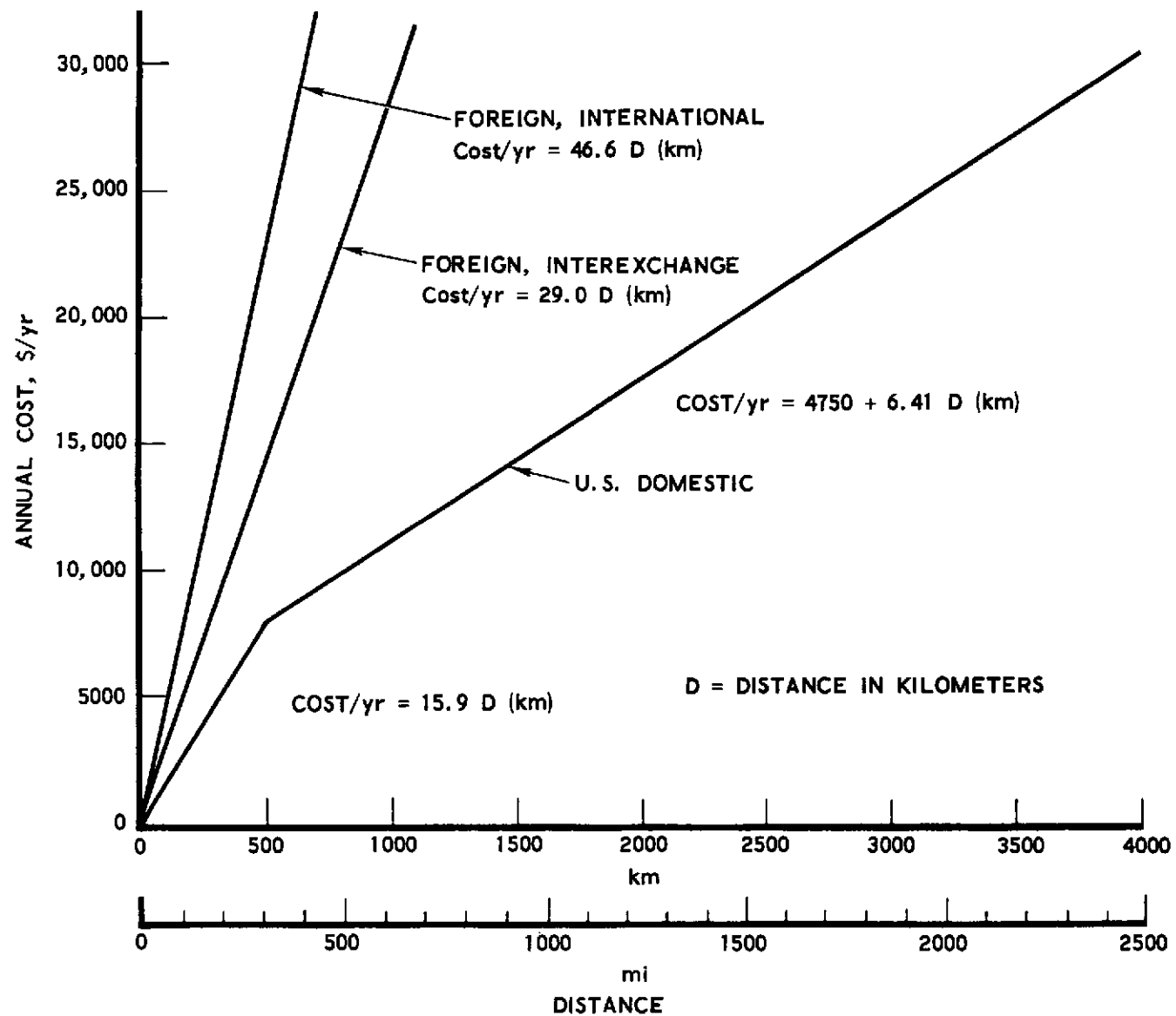


Figure 5-1. Leased Duplex Voice Circuit Costs, Overland 1973

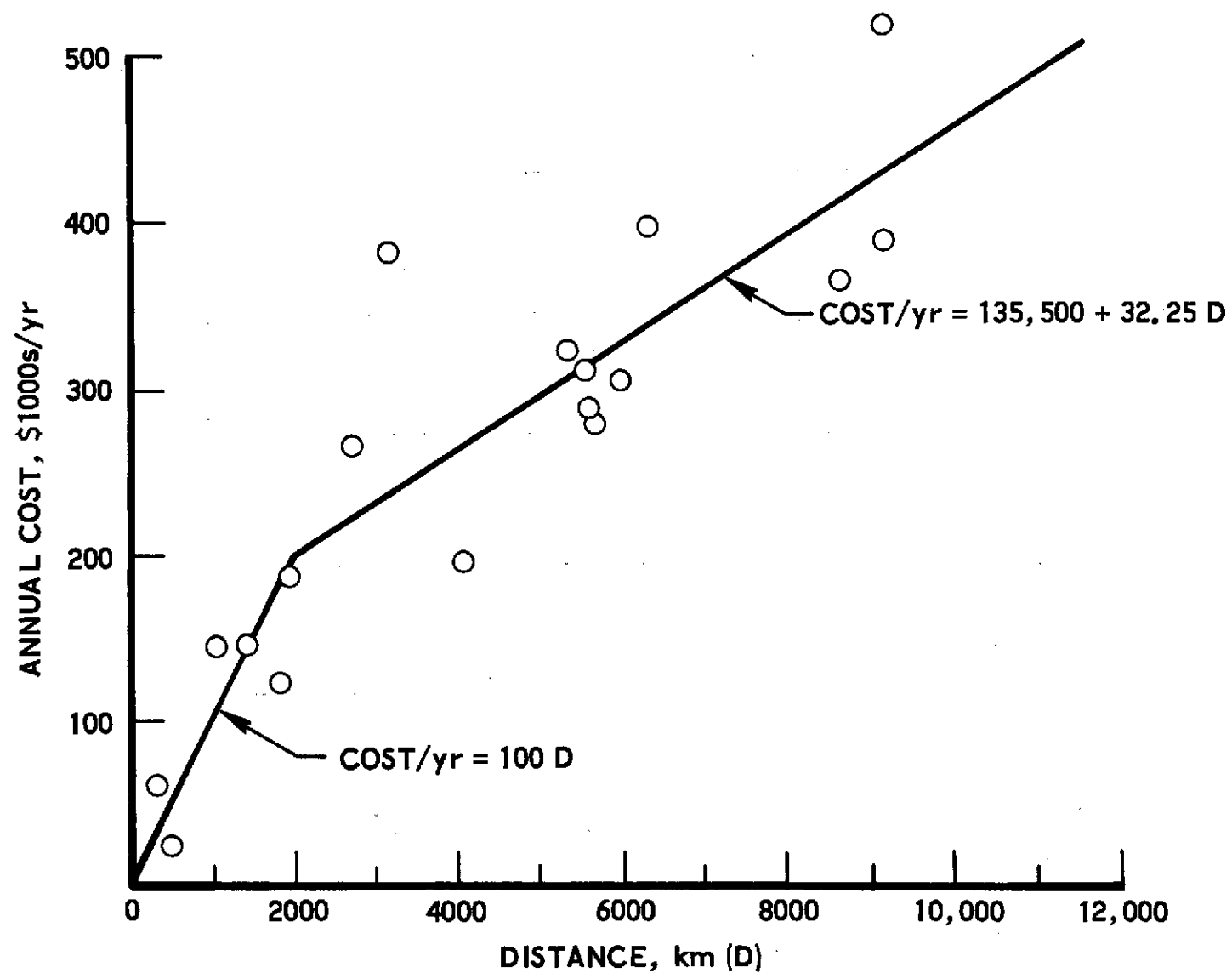
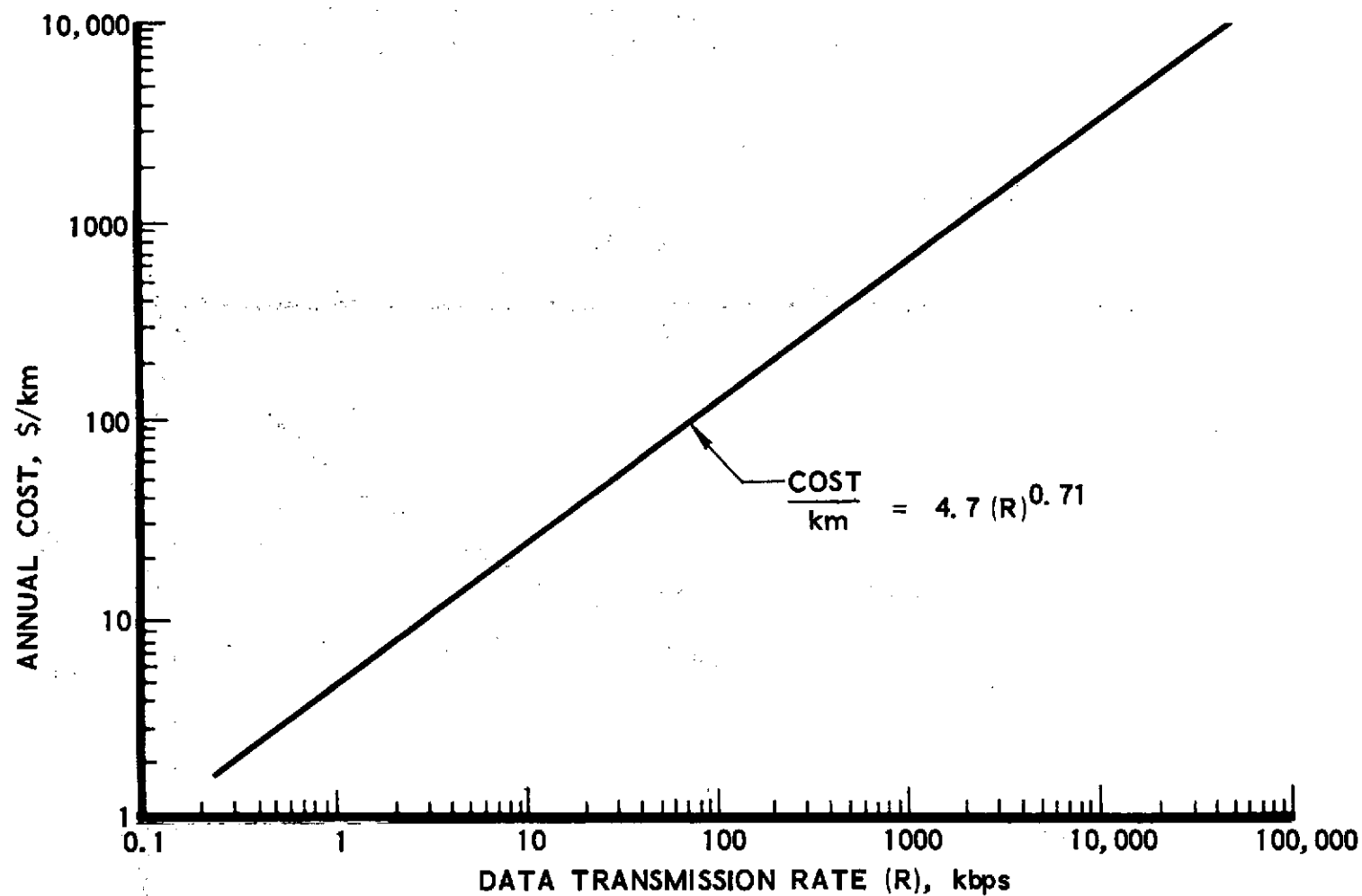


Figure 5-2. Leased Duplex Voice Circuit Costs, Transoceanic, 1973

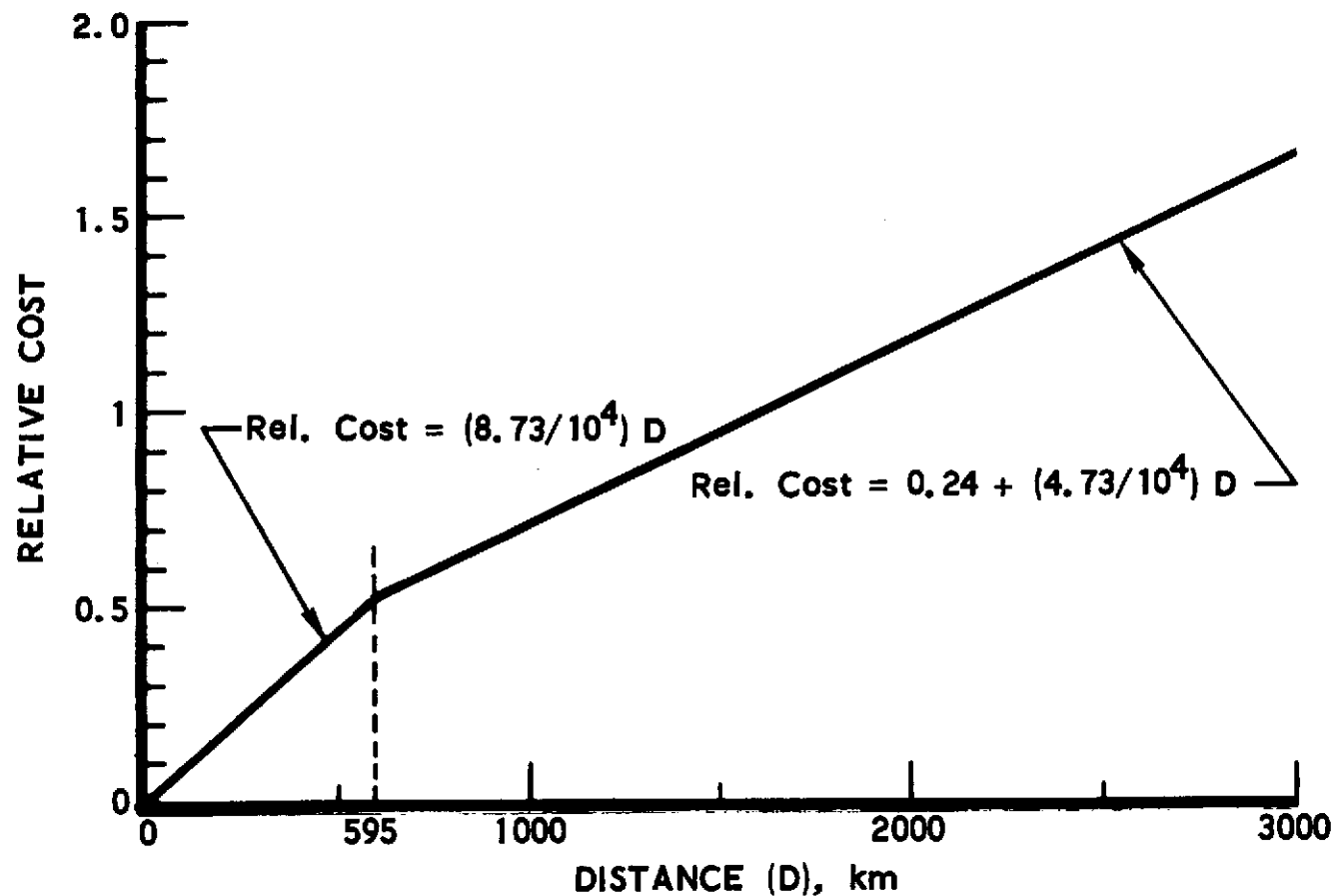
Table 5-4. Trend Factors for Adjusting Communications Costs for Future Years

Calendar Year	y (year-1973)	Trend Factor $(0.96)^y$
1973	0	1.00
1974	1	0.96
1975	2	0.92
1976	3	0.88
1977	4	0.85
1978	5	0.82
1979	6	0.78
1980	7	0.75
1981	8	0.72
1982	9	0.69
1983	10	0.66
1984	11	0.64
1985	12	0.61
1986	13	0.59
1987	14	0.56
1988	15	0.54
1989	16	0.52
1990	17	0.50
1991	18	0.48
1992	19	0.46
1993	20	0.44
1994	21	0.42
1995	22	0.41
1996	23	0.39
1997	24	0.38
1998	25	0.36
1999	26	0.35
2000	27	0.33



Source: Intercity Services Handbook,  
AT&T Long Lines Department,  
Aug., 1973.

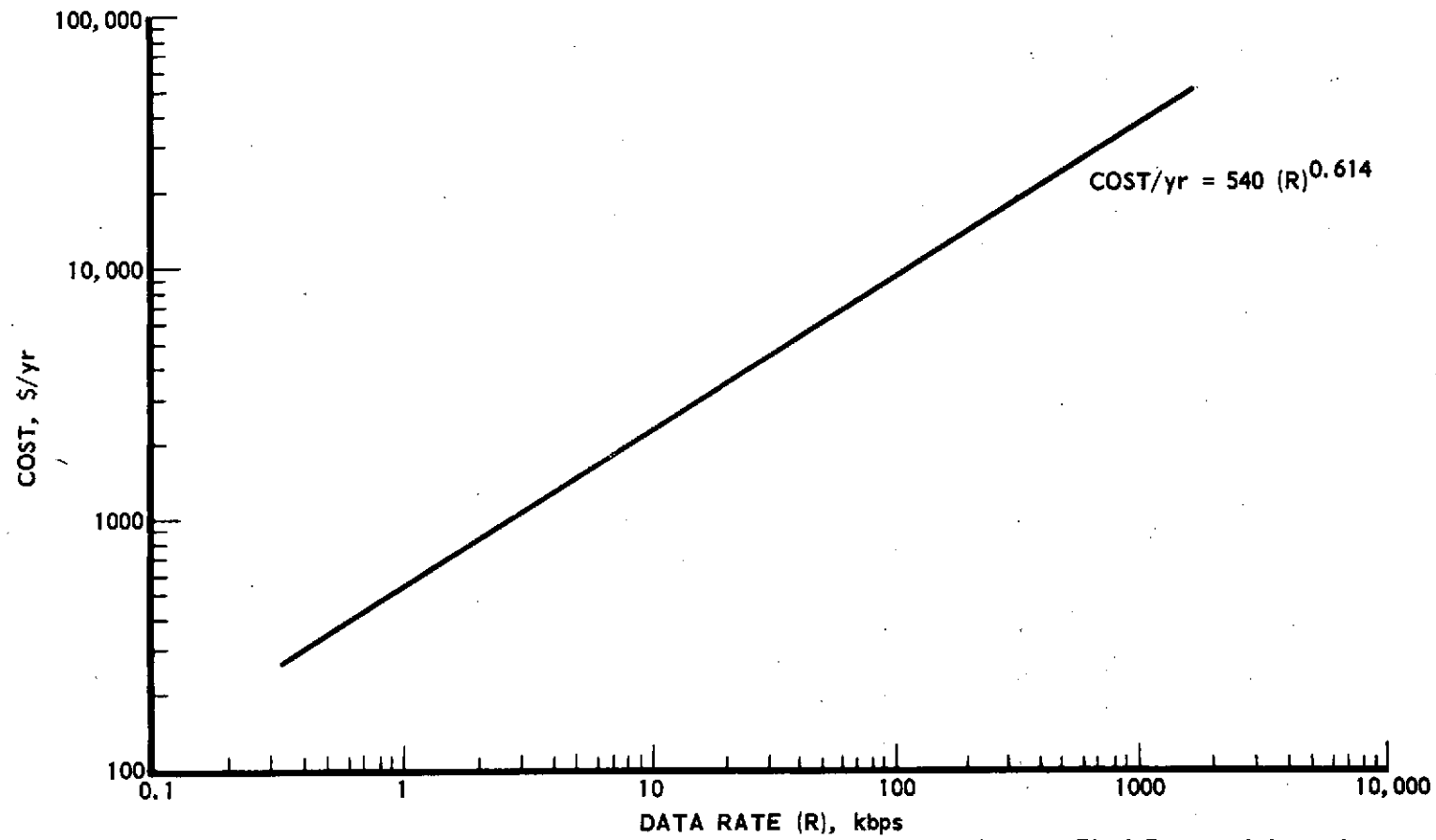
Figure 5-3. Communications Line Lease Cost/km vs Data Rate at  
1609 km (1000 mi), 1973



Source: Intercity Services Handbook,  
AT&T Long Lines Department,  
Aug., 1973, for 50 kbps channel,  
Series 8000.

Figure 5-4. Communication Line Lease Costs, Data Transmission  
Relative to Costs at 1609 km (1000 mi)





Source: Final Report, Information Transfer Satellite Concept Study, General Dynamics, Convair Aerospace Division, (15 May 1971).

Figure 5-5. Communication Terminal Equipment Lease Costs, Digital Data Transmission

#### 4. DEDICATED MICROWAVE RELAY SYSTEM

For dedicated communication circuits over land, where common carrier or specialized carrier facilities are not adequate, calculate costs of a microwave relay system dedicated to the mission. Relays in a typical system are spaced 48 km apart, on the average. Equipment for transmission of voice or data at a frequency of 4-6 GHz is assumed for basic calculations, and it is assumed that a switching system will be used in the interest of efficiency in utilizing transmission capability. Availability of 99.98 percent and P.01 service (no more than 0.01 probability that caller receives busy signal during the busiest hour of the day) are typical of these systems. The inputs required for calculation are:

- (1) Relay line distance in kilometers (D), or number of relay stations (R) at 48 kilometer spacing
- (2) Number of terminals (T)
- (3) Number of 4 KHz voice or 4000 bit-per-second data channels, each terminal ( $C_t$ )
- (4) Schedule of completions of terminals and relay stations.

If these inputs are not defined, they should be approximated. Relay trunk lines should be laid out on a map (or transparent overlays on Atlas maps) using the shortest single-line trunk to interconnect the terminal points (the same terminal points as specified for the comparable satellite system). The number of relay stations is calculated assuming one station every 48 km (30 mi) along the trunk routes between terminals. Communication traffic capacity for each terminal should be 30 percent greater than that specified for the system to allow for equipment outages<sup>(1)</sup>. The schedule of completions of terminals and the interconnecting relay stations should be consistent with the comparable satellite system schedule.

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(1) Satellite system nominal, or working, capacities are augmented, typically, by redundant capacity in spare satellites and earth stations of 50 to 100 percent of the nominal capacity to assure reliable service. Similarly, for microwave relay systems common carriers typically provide redundant capacity of 20 to 33 percent, which is approximated as 30 percent for the calculations herein.

Investment costs for relays and terminals are based on the following relationship (system design costs are included and development costs are not necessary for the equipment used):

$$\text{Cost} = R (\$184\text{K}) + \sum_{t=1}^{t=T} \$156\text{K} + (3.31\text{K}) (C_t)^{0.855} + (\$1.16\text{K}) (C_t)$$

where  $t$  is the terminal number, ranging from 1 to  $T$ .

Instead of calculating costs using this expression, costs for individual relay stations and terminals may be read directly from Figure 5-6 which shows the cost of relay stations and terminals versus terminal capacity in numbers of channels. The expression above is in terms of standard 4 kHz voice or equivalent data rate (4000 bps) channels; the effect of higher bit rate channels on cost is provided for by adjustments to the basic system cost in the calculations below. Additional adjustments allow for variations in construction cost according to geographic area.

To calculate system costs, use the worksheet, Table 5-5, to calculate investment costs of relay stations and terminals and the worksheet, Table 5-6, to summarize annual costs by year (in 1973 dollars) for input to the cost effectiveness analysis. For convenience of calculation, group terminals with the same capacity, year of completion, and construction cost factor; group relays with the same year of completion and construction cost factor.

Calculate costs in 1973 dollars for relays and terminals on the worksheet, Table 5-5, as follows:

1. Enter the numbers of terminals and relay stations, appropriately grouped according to year of completion, terminal capacity, and construction cost factor.
2. Calculate costs of terminals.
  - a. Determine unit cost per terminal according to channel capacity (Figure 5-6).
  - b. Calculate "basic cost" of individual terminals or groups of terminals by multiplying together the unit cost, the number of terminals in the group, and the construction cost factor.

- c. Calculate incremental costs due to use of channels with capacity different from the standard 4 kbps assumed in calculating basic costs. Incremental costs are the product of the basic cost, the fraction or percentage of channels capable of "B" kbps, and the capacity cost factor from Figure 5-7. Repeat calculation for additional non-standard channels of different capacity.
  - d. Sum the basic cost and incremental cost and multiply by the time factor,  $(0.96)^n$ , which reflects the downward trend of costs with advancing technology.
3. Calculate costs for relay stations in the same manner as for terminals. Note that unit costs do not vary with the number of channels carried or with capacity per channel.

Sum the investment costs of relays and terminals on the worksheet, Table 5-6.

1. Enter costs for terminals and relays from Table 5-5 in the year prior to the year of completion and calculate total investment and cumulative investment for each year. Retire investment (subtract out) after 20 years of operation to determine the investment in operating stations (terminals and relays).
2. Calculate annual operating costs for each year by multiplying the investment in operating stations for the prior year by 14 percent.

Note: The reader interested in source data for dedicated line-of-sight microwave relay systems should refer to Section 9, Part 4, of Volume IV of this Final Report.

## 5. CALCULATION OF SUBMARINE TELEPHONE CABLE SYSTEM COSTS

Where terrestrial communication links must cross oceans, submarine telephone cable systems offer the most economical choice. Communication system costs in such cases will be the sum of costs for the overland parts of the system using a microwave relay system and

Table 5-5. Worksheet, Investment Costs, Line-of-Sight Microwave Relay System

TERMINALS

Year (1)	"n" (2)	Designation (3)	No. Of Chan. Per Term. (4)	Unit Cost (Fig. 5-6)	Qty. (5)	Constr. Cost Factor (Table 4-9)	Basic Cost (6)	Incremental Costs For Other Data Rates/Chan.				Total, Basic Cost + $\Delta$	Time Factor $(0.96)^n$ (11)	Total Cost (1973\$) (12)
								Data Rate bps (7)	% (8)	$F_c$ (9)	\$ $\Delta$ (10)			

RELAY STATIONS (13)

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Footnotes: See next page.

Table 5-5. Worksheet, Investment Costs, Line-of-Sight  
Microwave Relay System (Cont'd)

Footnotes:

- (1) Year of construction completion.
- (2)  $n = (\text{year of construction completion}) - (1973)$
- (3) Any convenient designation of individual terminals or relay stations, or groups of terminals of the same capacity and construction cost factor, or groups of relays with the same construction cost factor.
- (4) Capacity per terminal, number of channels.
- (5) Number of terminals or channels being calculated as a group.
- (6) Basic cost, assuming standard 4 kHz voice or 4000 bps data channels.
- (7) Data rate per channel, in bits-per-second, for non-standard channels. If more than one non-standard data rate, use additional line(s) for calculation.
- (8) Ratio, number of non-standard channels of a particular data rate to the total number of channels, expressed as a percent.
- (9)  $F_c$  = channel capacity cost factor. See Figure 5-7.
- (10) Incremental cost due to non-standard channels = (basic cost) x (%) x  $(F_c - 1)$ .
- (11) Time factor to reduce costs four percent per year to reflect trend of technology advances.
- (12) Total cost (1973 dollars) = (time factor) x (total basic cost +  $\Delta$ 's) for terminals, or (time factor) x (basic cost) for relay stations.
- (13) Column headings for calculating relay station costs are the same as for terminals, except for the 4th and 9th through 13th columns, which are not required in relay station calculations.

Table 5-6. Worksheet, Line-of-Sight Microwave Relay Communications System Costs

INVESTMENT<sup>(1)</sup>

Geographic Area \ Year											
Total Investment/Year											
Cumulative Investment											
Less Retirements <sup>(2)</sup>											
Investment, Operating Stations											
Annual Operations <sup>(3)</sup>											

- (1) From Worksheet, Table 5-5. Apportion investment costs to year prior to first operation for each terminal or relay. Investment life = 20 years.
- (2) Retire investment from 20 years previous (if any).
- (3) 14 percent of investment, operating stations, for the preceding year.

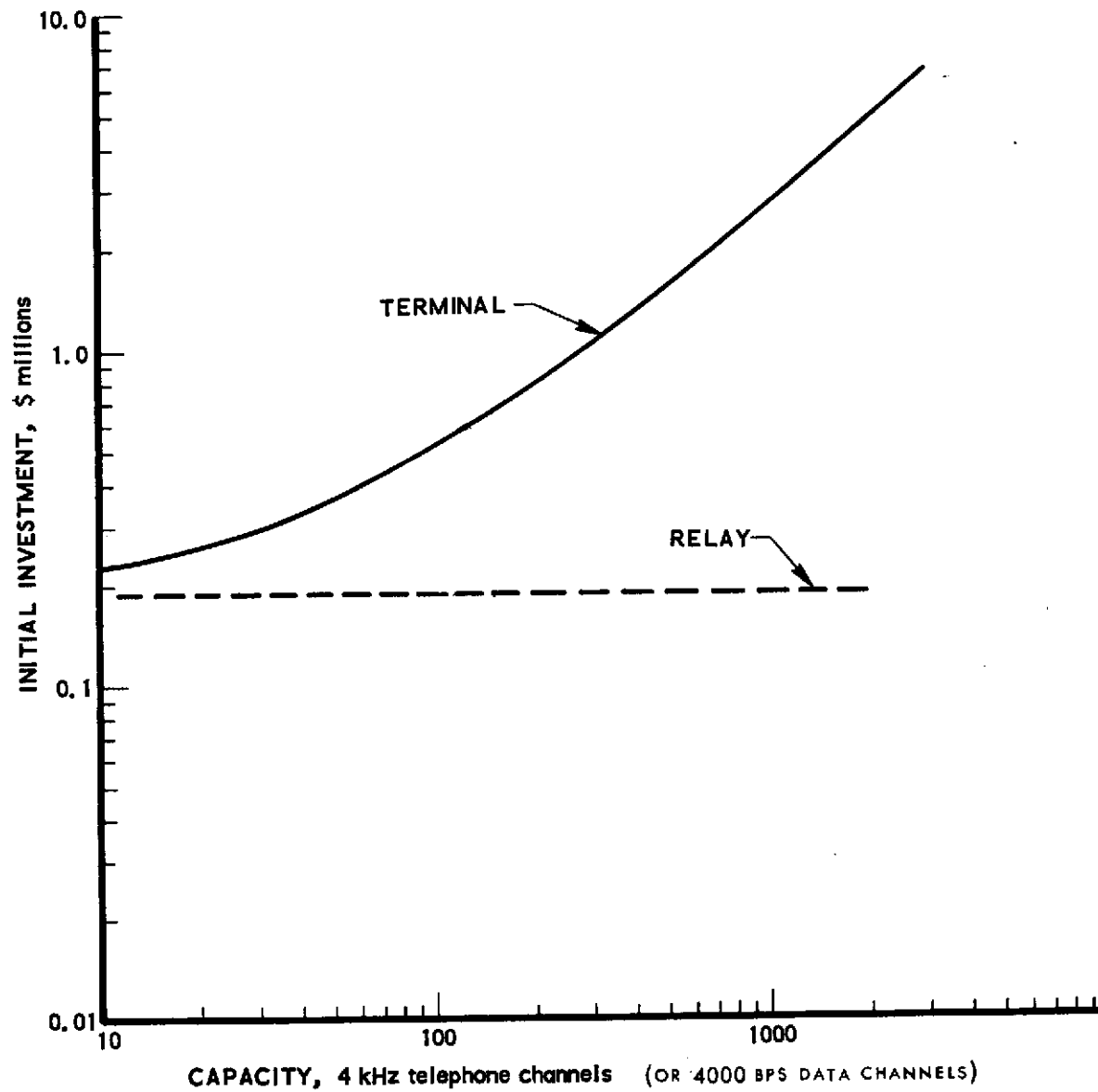


Figure 5-6. Line-of-Sight Microwave Relay Station and Terminal Investment Cost vs Capacity



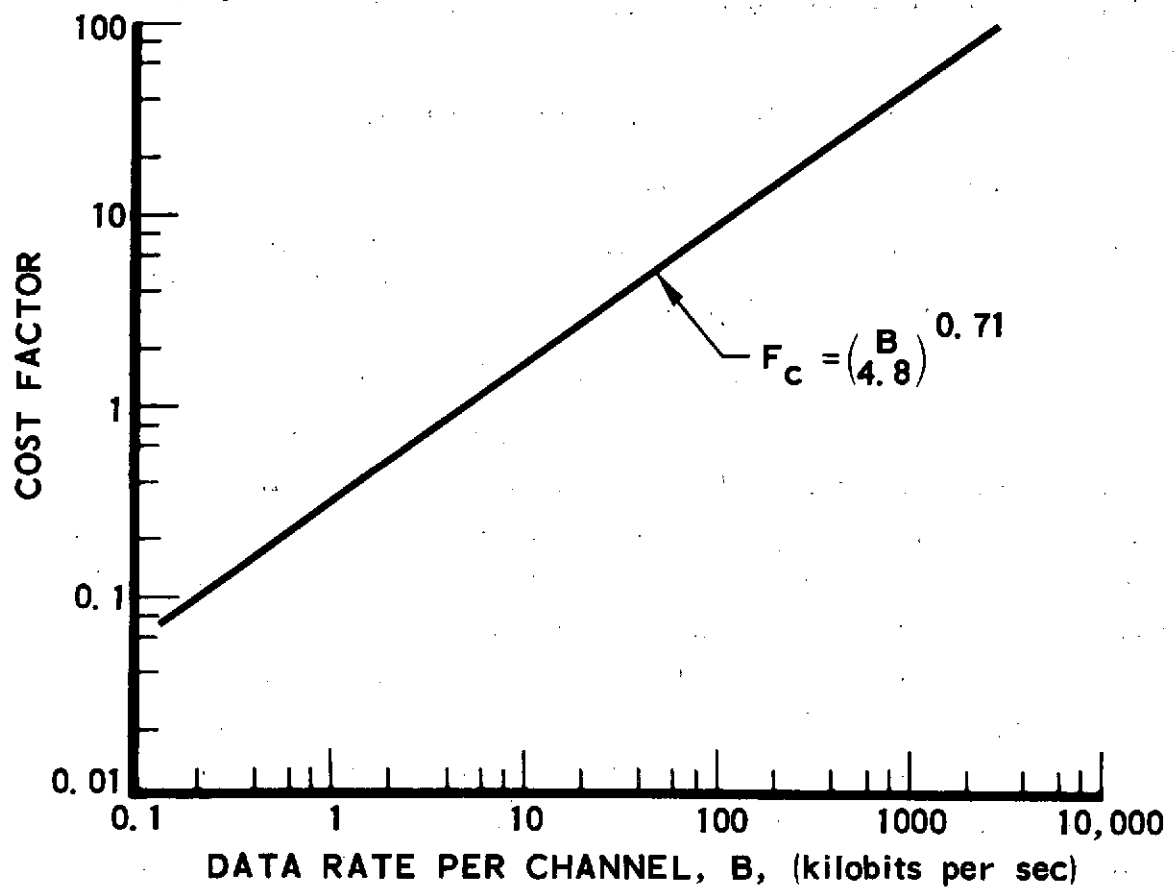


Figure 5-7. Capacity Cost Factor, Microwave Relay System Terminals

the transoceanic submarine telephone cable system, consisting of the cable itself, repeaters every 10 to 15 km (approximately 6 to 10 mi), and one terminal at each end which interfaces the overland system.

a. Investment Costs

Investment costs are calculated using the worksheet, Table 5-7. For each cable the following inputs must be provided and entered on the worksheet:

- (1) The cable terminal points (for identification)
- (2) The first year in service
- (3) The capacity in number of 4 kHz\* half-circuits (two half-circuits, or channels, one-way each, are required for a two-way telephone circuit)
- (4) The length of cable between terminals, in kilometers.

The unit investment cost per half-circuit per kilometer is read from Figure 5-8 and entered on the worksheet. Four cost curves are shown in the figure, for 1970, 1980, 1990, and 2000, indicating an estimated 3.1 percent per year decline in investment costs. Unit investment cost points for other years should be interpolated. For example, the unit investment cost for a 10,000 half-circuit cable system, first operational in 1996, would be \$13.50, about six-tenths of the distance from the 1990 curve down toward the 2000 curve on the line for 10,000 half-circuits. Asterisks at the ends of the cost curves indicate the approximate capacity limits for single cables in 1970, 1980, and 1990.

The length factor is read from Figure 5-9 for the cable length and entered on the worksheet. This factor is used to adjust the investment costs per unit length from Figure 5-8, which are normalized to 4000 kilometers, for other cable lengths.

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\* Note that the usual submarine cable telephone half-circuit bandwidth is 3 kHz. Calculations herein are based on 4 kHz bandwidths for comparability with overland and satellite systems.

Table 5-7. Worksheet, Submarine Telephone Cable  
Communications System Investment Costs,  
1973 Dollars

Column No. →						
Cable Terminal Points	Inputs			Cost Per Half- Circuit per km (Fig. 5-8)	Length Factor (Fig. 5-9)	Investment Cost 2x3x4x5
	1st Year In Service	Capacity, No. Half- Circuits	Length (km)			

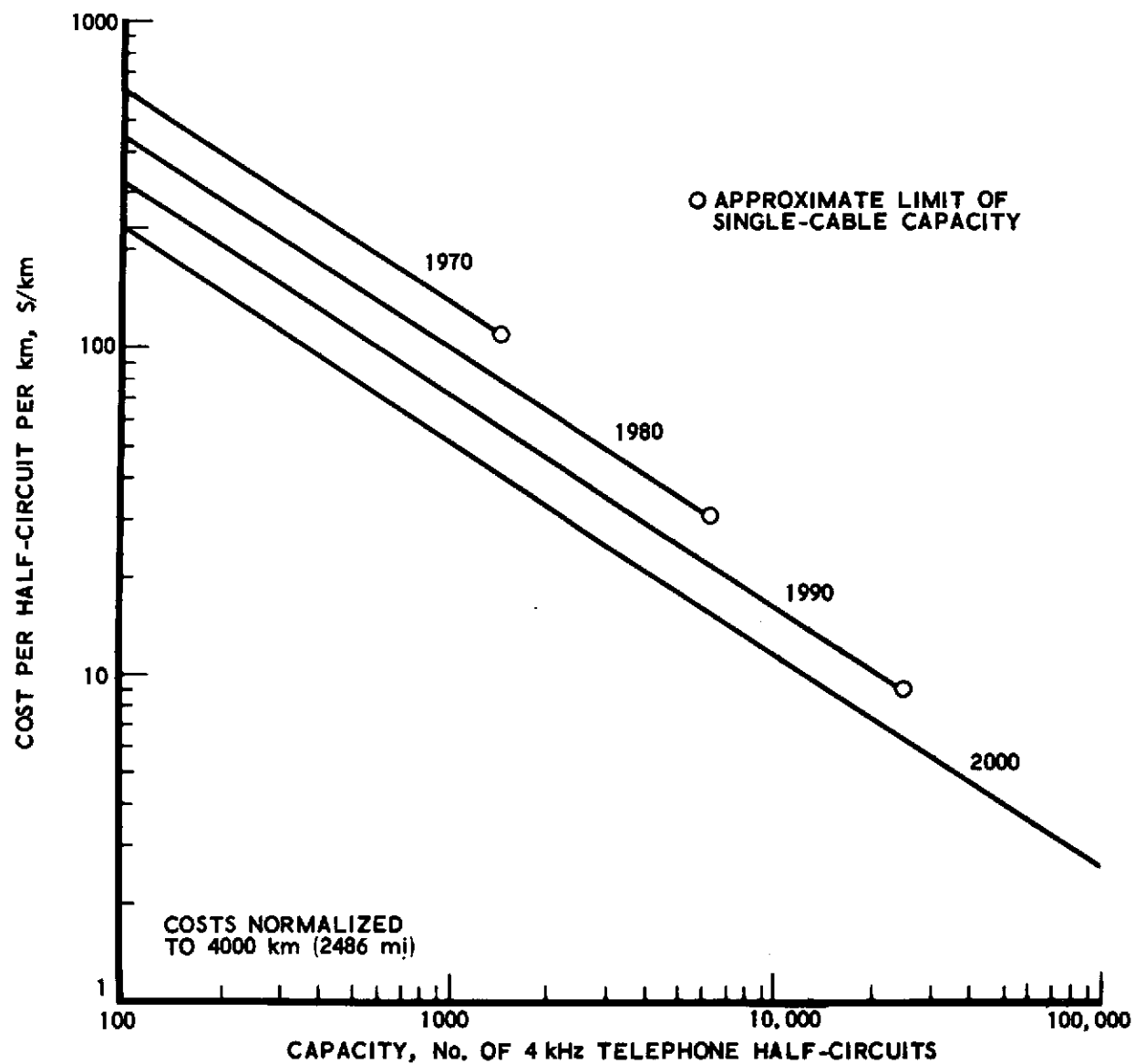


Figure 5-8. Investment Cost of Submarine Telephone Cable Per Half-Circuit Per Kilometer (1973 Dollars)

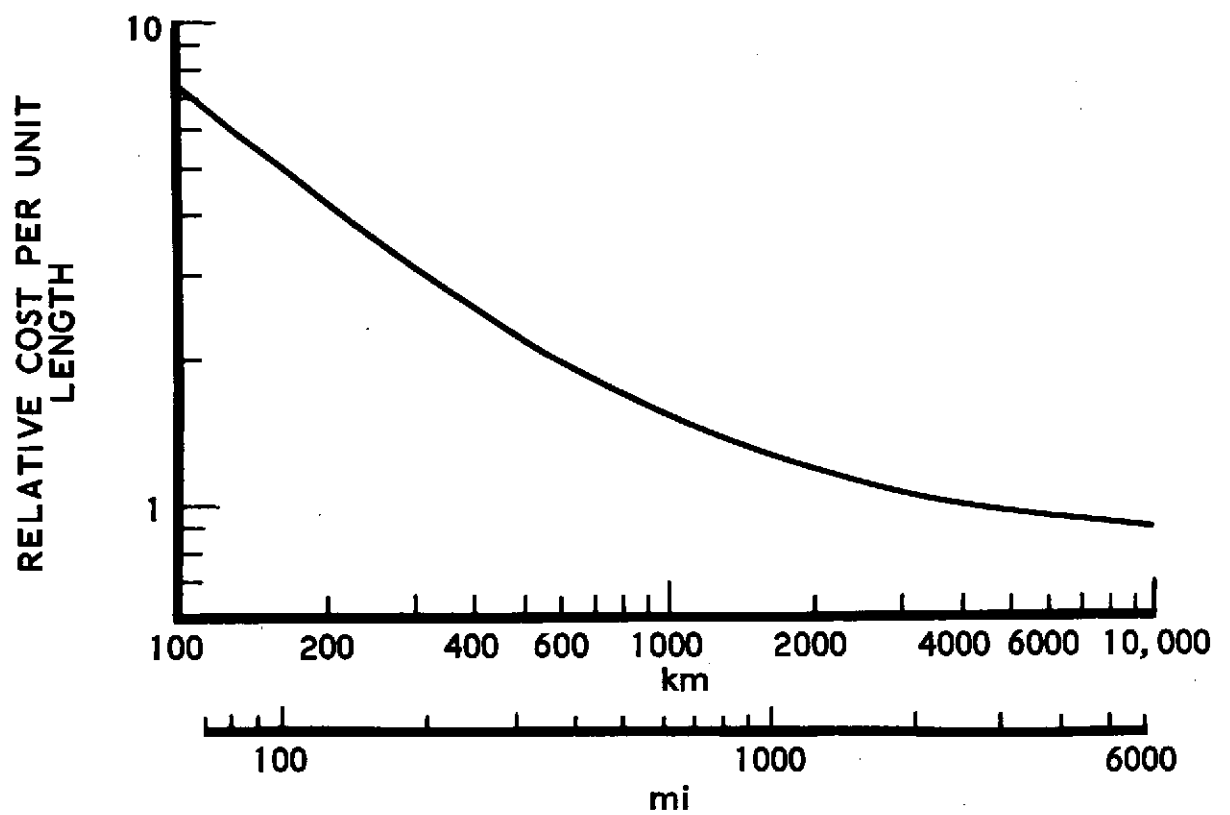


Figure 5-9. Relative Cost Per Unit Length vs Length for Submarine Telephone Cable Systems

The cable system cost is then calculated in the right-hand column of Table 5-7 by multiplying together the unit cost per half-circuit per kilometer, the capacity in half-circuits, the length in kilometers, and the length factor.

The worksheet, Table 5-8, is used to show costs in the year of expenditure. The investment cost determined in Table 5-7 for each cable system should be allocated approximately in the proportions 2:4:4 to the third, second, and first year, respectively, prior to the year of first operation. Use a 24-year service life as the basis for estimating residual values where cable useful life exceeds the time period for which cost comparisons are made.

Operating costs for each year of service life are calculated by multiplying the cable system investment cost by 8.5 percent. These operating costs include the costs of maintaining and operating the cable and terminal facilities, 2.8 percent, and personnel costs for servicing customers' requirements, accounting, billing, advertising, etc., 5.6 percent of investment.

#### B. U. S. POSTAL SERVICE COSTS

Transmission of information by a satellite system is an alternative to transmission using mail. Mail service is relatively much slower than telecommunication by satellite; however, in cases where realtime, or near realtime transmission is not a paramount requirement, the lower cost, slower but still reliable mail may be attractive.

Calculating the relative cost effectiveness of satellite systems and mail service requires placing a value on time of communication. It is not practicable to determine this value in the procedures herein because the value of time varies with the nature and use of the information transmitted. In some cases the value of time far outweighs cost differences, e.g., TV coverage of daily news or sports events of national interest. In

Table 5-8. Worksheet, Submarine Telephone Cable Communication System Investment Costs, By Year (1973 Dollars)

Cable Terminal Points	Investment Or Operating Cost <sup>(1)</sup>	Year													
		—	—	—	—	—	—	—	—	—	—	—	—	—	—
Total Investment															
Total Operating															

(1) A 24-year service life should be assumed in calculating replacement times or residual values.

other cases time is less critical and relative cost of alternative transmission or transportation is important, e. g., CATV showing of special features or movies.

The costs of information transmission by mail can be calculated using the procedures below with sufficient accuracy to provide a basis for cost comparison with satellite system transmission. Comparisons of effectiveness will depend on the purpose of the satellite system communications.

Postal Service mail classifications and rates are complex, owing to variations in priority of handling, size and weight of pieces of mail, quantity per mailing, distance covered, transportation mode, and preferences granted in the public interest to some senders and some kinds of mail. In addition, a large proportion of total costs are costs for facilities used in common for all mail classes, and the allocation of these costs to determine rates has been necessarily arbitrary.

Thus, simple relationships between parameters such as weight, distance, priority of handling, or quantity per mailing and the rates charged are not adequate to describe the rate variations for all classes of mail. To determine the cost of mail service, it is necessary to segregate mail by mail class and determine costs by mail class. Simplified relationships are used herein to approximate the actual Postal Service rate schedules for particular classes of mail in the interest of simplifying calculations.

## 1. INPUTS REQUIRED

In order to determine mail classifications, the following information must be provided in the system definition:

- (1) Nature of business of sender - non-profit publisher, publisher of classroom materials, library, mail-order retailer, etc.
- (2) Kind of material - advertising, general reading matter, books, magazines, etc.



- (3) Weight per piece or a range or distribution of weights per piece.
- (4) Quantity mailed per year, number of pieces, weight.
- (5) Distance to destination or the quantities of mail to several destination distances.

## 2. SELECTION OF MAIL CLASSIFICATION

Table 10-2 in Volume IV, Part 4, Section 10, provides a basis for relating the characteristics of the sender and the nature of the mail to the major mail classes and sub-classes. Select the appropriate classification and calculate mailing costs using the worksheets in Part 3 of Volume IV for the appropriate classification.

## 3. CALCULATION OF MAILING COSTS

Calculate annual costs for mailing using the worksheets in:

- (1) Table 5-9 for first class and air mail
- (2) Table 5-10 for priority mail
- (3) Table 5-12 for second class publications
- (4) Table 5-13 for parcel post (fourth-class).

Summarize costs per year in Table 5-15.

## C. AIRCRAFT COSTS

The specific objectives of earth observation missions and the sensors used will determine payload requirements for the aircraft, the width of observation strip, the observation altitude, restrictions on suitable times of day or year for observation, and so on, all of which will affect, in one way or another, the selection of aircraft, their numbers, and their initial costs or operating costs.

It is not practicable to anticipate all possible missions and to devise uncomplicated procedures for selecting specific aircraft to satisfy mission requirements and for estimating their costs. The procedures

Table 5-9. Worksheet, First Class and Air Mail, Annual Costs

INPUTS REQUIRED

For first class and for airmail, enter in tabulation, below:

1. Number of pieces per year for each year
2. Average weight per piece<sup>(1)</sup>

CALCULATIONS

FIRST CLASS

No. of Pieces (N)

Avg. Wt/Piece (W), oz

Cost = (N) (W) (\$0.10)


AIR MAIL

No. of Pieces (N)

Avg. Wt/Piece(W), oz

Cost = (N) (W) (\$0.13)


(1) Maximum weights: first class, 12 oz; airmail 8 oz.

Table 5-10. Worksheet, Priority Mail, Annual Costs

ALTERNATIVE PROCEDURES:

- (a) Enter inputs required in Alternative (a) below:
- Weight/year in 1 to 5-pound packages, for each distance
  - Weight/year in packages >5 pounds, for each distance.
- (b) Enter inputs required in Alternative (b), next page:
- Weight per piece
  - Number of pieces per year to each distance

Alternative (a), Costs for Year \_\_\_\_\_

Weight Per Piece (lb)	Distance - Miles Postal Zone	<250	250-600	600-1000	1000-1400	1400-1850	>1850	Total
		Loc. 1, 2, 3	4	5	6	7	8	
1 - 5 lb	Wt/Year (lb)							
	Cost/Lb	\$0.71	\$0.73	\$0.78	\$0.84	\$0.90	\$0.96	
	Cost/Year*							
More Than 5 lb	Wt/Year (lb)							
	Cost/Lb	\$0.50	\$0.52	\$0.58	\$0.66	\$0.73	\$0.81	
	Cost/Year*							

\* Cost/Year = (wt/year in lb) (cost/lb)

Table 5-10. Worksheet, Priority Mail, Annual Costs (Cont'd)

ALTERNATIVE PROCEDURES:

(b) Enter inputs required in Alternative (b) below:

- Weight per piece
- Number of pieces per year to each distance.

Alternative (b), Costs for Year \_\_\_\_\_

Weight Per Piece (lb)	Distance - Miles Postal Zone	250	250-600	600-1000	1000-1400	1400-1850	1850	Total
		Loc. 1, 2, 3	4	5	6	7	8	
	No. Pieces/Year Cost/Piece* Cost/Year**							
	No. Pieces/Year Cost/Piece Cost/Year							
	No. Pieces/Year Cost/Piece Cost/Year							
	No. Pieces/Year Cost/Piece Cost/Year							
	No. Pieces/Year Cost/Piece Cost/Year							
Total Cost/Year								

\* From Table 5-11.

\*\* Cost/Year = (No. pieces/year) (cost/piece)

Table 5-11. Priority Mail Rates

Weight over 8 ounces and not exceed- ing: (Lbs.)	RATE					
	Local Zones 1, 2, and 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8
1 ....	1.00	1.00	1.00	1.00	1.00	1.00
1-½ ..	1.20	1.22	1.25	1.30	1.40	1.50
2 ....	1.40	1.43	1.51	1.60	1.68	1.77
2-½ ..	1.60	1.65	1.76	1.90	2.02	2.16
3 ....	1.80	1.86	2.01	2.20	2.36	2.54
3-½ ..	2.00	2.08	2.26	2.49	2.69	2.93
4 ....	2.20	2.30	2.52	2.79	3.03	3.31
4-½ ..	2.40	2.51	2.77	3.09	3.37	3.70
5 ....	2.60	2.73	3.02	3.39	3.71	4.08
6 ....	3.08	3.23	3.58	4.03	4.43	4.88
7 ....	3.56	3.73	4.14	4.67	5.15	5.68
8 ....	4.04	4.23	4.70	5.31	5.87	6.48
9 ....	4.52	4.73	5.26	5.95	6.59	7.28
10 ....	5.00	5.23	5.82	6.59	7.31	8.08
11 ....	5.48	5.73	6.38	7.23	8.03	8.88
12 ....	5.96	6.23	6.94	7.87	8.75	9.68
13 ....	6.44	6.73	7.50	8.51	9.47	10.48
14 ....	6.92	7.23	8.06	9.15	10.19	11.28
15 ....	7.40	7.73	8.62	9.79	10.91	12.08
16 ....	7.88	8.23	9.18	10.43	11.63	12.88
17 ....	8.36	8.73	9.74	11.07	12.35	13.68
18 ....	8.84	9.23	10.30	11.71	13.07	14.48
19 ....	9.32	9.73	10.86	12.35	13.79	15.28
20 ....	9.80	10.23	11.42	12.99	14.51	16.08
21 ....	10.28	10.73	11.98	13.63	15.23	16.88
22 ....	10.76	11.23	12.54	14.27	15.95	17.68
23 ....	11.24	11.73	13.10	14.91	16.67	18.48
24 ....	11.72	12.23	13.66	15.55	17.39	19.28
25 ....	12.20	12.73	14.22	16.19	18.11	20.08
26 ....	12.68	13.23	14.78	16.83	18.83	20.88
27 ....	13.16	13.73	15.34	17.47	19.55	21.68
28 ....	13.64	14.23	15.90	18.11	20.27	22.48
29 ....	14.12	14.73	16.46	18.75	20.99	23.28
30 ....	14.60	15.23	17.02	19.39	21.71	24.08
31 ....	15.08	15.73	17.58	20.03	22.43	24.88
32 ....	15.56	16.23	18.14	20.67	23.15	25.68
33 ....	16.04	16.73	18.70	21.31	23.87	26.48
34 ....	16.52	17.23	19.26	21.95	24.59	27.28
35 ....	17.00	17.73	19.82	22.59	25.31	28.08

Weight over 8 ounces and not exceed- ing: (Lbs.)	RATE					
	Local Zones 1, 2, and 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8
36 ....	17.48	18.23	20.38	23.23	26.03	28.88
37 ....	17.96	18.73	20.94	23.87	26.75	29.68
38 ....	18.44	19.23	21.50	24.51	27.47	30.48
39 ....	18.92	19.73	22.06	25.15	28.19	31.28
40 ....	19.40	20.23	22.62	25.79	28.91	32.08
41 ....	19.88	20.73	23.18	26.43	29.63	32.88
42 ....	20.36	21.23	23.74	27.07	30.35	33.68
43 ....	20.84	21.73	24.30	27.71	31.07	34.48
44 ....	21.32	22.23	24.86	28.35	31.79	35.28
45 ....	21.80	22.73	25.42	28.99	32.51	36.08
46 ....	22.28	23.23	25.98	29.63	33.23	36.88
47 ....	22.76	23.73	26.54	30.27	33.95	37.68
48 ....	23.24	24.23	27.10	30.91	34.67	38.48
49 ....	23.72	24.73	27.66	31.55	35.39	39.28
50 ....	24.20	25.23	28.22	32.19	36.11	40.08
51 ....	24.68	25.73	28.78	32.83	36.83	40.88
52 ....	25.16	26.23	29.34	33.47	37.55	41.68
53 ....	25.64	26.73	29.90	34.11	38.27	42.48
54 ....	26.12	27.23	30.46	34.75	38.99	43.28
55 ....	26.60	27.73	31.02	35.39	39.71	44.08
56 ....	27.08	28.23	31.58	36.03	40.43	44.88
57 ....	27.56	28.73	32.14	36.67	41.15	45.68
58 ....	28.04	29.23	32.70	37.31	41.87	46.48
59 ....	28.52	29.73	33.26	37.95	42.59	47.28
60 ....	29.00	30.23	33.82	38.59	43.31	48.08
61 ....	29.48	30.73	34.38	39.23	44.03	48.88
62 ....	29.96	31.23	34.94	39.87	44.75	49.68
63 ....	30.44	31.73	35.50	40.51	45.47	50.48
64 ....	30.92	32.23	36.06	41.15	46.19	51.28
65 ....	31.40	32.73	36.62	41.79	46.91	52.08
66 ....	31.88	33.23	37.18	42.43	47.63	52.88
67 ....	32.36	33.73	37.74	43.07	48.35	53.68
68 ....	32.84	34.23	38.30	43.71	49.07	54.48
69 ....	33.32	34.73	38.86	44.35	49.79	55.28
70 ....	33.80	35.23	39.42	44.99	50.51	56.08

Table 5-12. Worksheet, Second Class Mail, Annual Cost

INPUTS REQUIRED

- Classification<sup>(1)</sup>. Line out the two columns of rates not used
- Total weight of publications/year by distance or postal zone
- No. of pieces/year, enter in table
- No. pounds reading matter/year, enter in table

CALCULATIONS

			Years →					
Rates ¢/Lb <sup>(1)</sup>			Weight (lb)	Cost (\$)	Weight (lb)	Cost (\$)	Weight (lb)	Cost (\$)
Z	C1	NP						
4.0	2.3	2.4						

1. Reading Matter

1. Reading Matter

2. Advertising

Zone	Distance (Miles)									
1&2	50-125	6.0	3.6	4.4						
3	125-250	7.2	4.4	5.2						
4	250-600	9.6	5.9	6.9						
5	600-1000	11.9	7.4	8.6						
6	1000-1400	14.4	9.0	9.4						
7	1400-1850	15.3	9.5	9.5						
8	1850 & Up	17.8	11.1	9.7						
Total Advertising:										

3. Per-Piece Cost

Rates, ¢ Each								
Z	C1	NP	# Pcs.	Cost \$	# Pcs.	Cost \$	# Pcs.	Cost \$
0.2	0.1	0.04						

4. Minimum Total Costs

1.3	0.8	0.2						
-----	-----	-----	--	--	--	--	--	--

5. Total Calculated Cost  
(1 + 2 + 3)

--	--	--

6. Total Cost (Larger of 4 or 5)

--	--	--

(1) Regular zone-rate publications (Z), classroom publication (C1), or non-profit publications (NP)

Table 5-13. Worksheet, Parcel Post, Annual Cost

ALTERNATIVE PROCEDURES:

- (a) Enter inputs required in Alternative (a) below:
- Weight per year to each distance
  - Number of pieces per year to each distance.
- (b) Enter inputs required in Alternative (b), next page
- Weight per piece
  - No. of pieces per year to each distance

Alternative (a), Costs for Year \_\_\_\_\_

	Distance (Miles) →	< 50	50-125	125-250	250-600	600-1000	1000-1400	1400-1850	> 1850	Total
		Postal Zone →	Local	1, 2	3	4	5	6	7	
Costs For Weight	Wt. /Year (lb)									
	Cost/Lb		\$0.036	\$0.067	\$0.076	\$0.078	\$0.121	\$0.150	\$0.188	\$0.203
	Cost/Year*									
Per-Piece Costs	No. Pieces/Year									
	Cost/Piece		\$0.55	\$0.600	\$0.680	\$0.800	\$0.850	\$0.900	\$0.950	\$1.000
	Cost/Year**									
TOTAL:										

\* Cost/year = (weight/year) (cost/lb)

\*\* Cost/year = (no. pieces/year) (cost/piece)

Table 5-13. Worksheet, Parcel Post, Annual Cost (Cont'd)

ALTERNATIVE PROCEDURES:

(b) Enter inputs required in Alternative (b), below:

- Weight per piece
- No. of pieces per year to each distance

Alternative (b), Costs for Year \_\_\_\_\_

Weight/ Piece (lb)	Distance (Miles) →	50	50-125	125-250	250-600	600-1000	1000- 1400	1400- 1850	1850	Total
	Postal Zone →	Local	1,2	3	4	5	6	7	8	
	No. Pieces/Year Cost/Piece*									
	No. Pieces/Year Cost/Piece									
	No. Pieces/Year Cost/Piece									
	No. Pieces/Year Cost/Piece									
* From Table 5-14.										
TOTAL:										



Table 5-14. Parcel Post Rates

Weight— 1 pound and not exceeding (pounds)	Zones							
	Local	1 and 2	3	4	5	6	7	8
2 ....	\$0.60	\$0.65	\$0.70	\$0.75	\$0.80	\$0.90	\$1.00	\$1.05
3 ....	.60	.75	.80	.85	.95	1.10	1.20	1.35
4 ....	.65	.80	.85	.95	1.10	1.30	1.40	1.60
5 ....	.70	.85	.90	1.05	1.20	1.45	1.65	1.90
6 ....	.70	.95	1.00	1.15	1.35	1.60	1.85	2.10
7 ....	.75	1.05	1.10	1.25	1.50	1.75	2.10	2.35
8 ....	.75	1.10	1.15	1.35	1.60	1.90	2.30	2.60
9 ....	.80	1.15	1.20	1.45	1.75	2.05	2.45	2.85
10 ....	.80	1.20	1.30	1.55	1.90	2.20	2.65	3.10
11 ....	.80	1.25	1.35	1.60	2.00	2.30	2.85	3.35
12 ....	.85	1.30	1.45	1.70	2.10	2.45	3.05	3.55
13 ....	.85	1.35	1.55	1.80	2.20	2.60	3.25	3.80
14 ....	.90	1.40	1.60	1.90	2.35	2.75	3.45	4.00
15 ....	.90	1.45	1.65	2.00	2.45	2.85	3.60	4.20
16 ....	.95	1.55	1.75	2.05	2.55	2.95	3.80	4.40
17 ....	1.00	1.60	1.80	2.15	2.65	3.10	3.95	4.60
18 ....	1.00	1.65	1.90	2.20	2.75	3.20	4.15	4.80
19 ....	1.05	1.70	2.00	2.30	2.85	3.35	4.30	5.00
20 ....	1.05	1.75	2.05	2.40	2.95	3.50	4.50	5.20
21 ....	1.10	1.85	2.10	2.45	3.05	3.65	4.65	5.40
22 ....	1.15	1.90	2.15	2.55	3.15	3.75	4.85	5.60
23 ....	1.15	1.95	2.20	2.60	3.25	3.90	5.00	5.80
24 ....	1.20	2.00	2.25	2.65	3.35	4.05	5.15	6.00
25 ....	1.20	2.05	2.30	2.75	3.45	4.15	5.35	6.20
26 ....	1.20	2.10	2.35	2.85	3.55	4.30	5.50	6.40
27 ....	1.25	2.15	2.40	2.90	3.70	4.45	5.65	6.60
28 ....	1.25	2.20	2.45	2.95	3.80	4.60	5.80	6.80
29 ....	1.30	2.25	2.50	3.05	3.90	4.70	5.95	7.00
30 ....	1.30	2.30	2.55	3.10	4.00	4.85	6.10	7.20
31 ....	1.35	2.35	2.65	3.20	4.10	5.00	6.25	7.40
32 ....	1.40	2.40	2.70	3.30	4.20	5.15	6.45	7.60
33 ....	1.40	2.45	2.75	3.35	4.30	5.25	6.60	7.80
34 ....	1.45	2.50	2.80	3.40	4.40	5.40	6.75	8.00
35 ....	1.45	2.55	2.85	3.45	4.50	5.55	6.90	8.20

Weight— 1 pound and not exceeding (pounds)	Zones							
	Local	1 and 2	3	4	5	6	7	8
36 ....	\$1.45	\$2.60	\$2.90	\$3.55	\$4.60	\$5.65	\$ 7.10	\$8.40
37 ....	1.50	2.65	3.00	3.65	4.70	5.75	7.25	8.60
38 ....	1.50	2.70	3.05	3.70	4.80	5.90	7.45	8.80
39 ....	1.55	2.75	3.10	3.80	4.90	6.05	7.60	9.00
40 ....	1.55	2.80	3.15	3.85	5.00	6.15	7.75	9.20

CONSULT POSTMASTER FOR WEIGHT AND SIZE LIMITS

41 ....	1.60	2.85	3.20	3.95	5.15	6.25	7.95	9.40
42 ....	1.65	2.90	3.25	4.00	5.25	6.40	8.10	9.60
43 ....	1.65	2.95	3.30	4.10	5.35	6.55	8.25	9.80
44 ....	1.70	3.00	3.35	4.15	5.45	6.65	8.40	10.00
45 ....	1.70	3.05	3.40	4.20	5.55	6.80	8.55	10.20
46 ....	1.70	3.10	3.50	4.30	5.65	6.90	8.70	10.40
47 ....	1.75	3.10	3.55	4.40	5.75	7.00	8.90	10.60
48 ....	1.75	3.15	3.60	4.45	5.85	7.15	9.05	10.80
49 ....	1.80	3.20	3.65	4.50	5.95	7.30	9.20	11.00
50 ....	1.80	3.25	3.70	4.60	6.05	7.40	9.35	11.15
51 ....	1.85	3.30	3.80	4.70	6.15	7.50	9.50	11.35
52 ....	1.90	3.35	3.85	4.75	6.25	7.65	9.65	11.55
53 ....	1.90	3.40	3.90	4.80	6.35	7.80	9.80	11.75
54 ....	1.95	3.40	3.95	4.90	6.45	7.90	9.95	11.90
55 ....	1.95	3.45	4.00	4.95	6.55	8.00	10.10	12.10
56 ....	1.95	3.50	4.10	5.05	6.60	8.10	10.25	12.25
57 ....	2.00	3.55	4.15	5.15	6.70	8.25	10.40	12.45
58 ....	2.00	3.60	4.20	5.20	6.80	8.40	10.55	12.60
59 ....	2.05	3.65	4.25	5.25	6.90	8.50	10.70	12.80
60 ....	2.05	3.65	4.30	5.35	7.00	8.60	10.85	12.95
61 ....	2.10	3.70	4.35	5.45	7.05	8.70	11.00	13.10
62 ....	2.15	3.70	4.40	5.50	7.15	8.85	11.15	13.30
63 ....	2.15	3.75	4.45	5.55	7.25	9.00	11.30	13.45
64 ....	2.20	3.80	4.50	5.60	7.35	9.10	11.45	13.65
65 ....	2.20	3.85	4.60	5.70	7.45	9.20	11.60	13.80
66 ....	2.20	3.90	4.65	5.80	7.50	9.30	11.75	13.95
67 ....	2.25	3.95	4.70	5.85	7.60	9.40	11.85	14.15
68 ....	2.25	3.95	4.75	5.90	7.70	9.55	12.00	14.30
69 ....	2.30	4.00	4.80	5.95	7.75	9.65	12.15	14.50
70 ....	2.30	4.05	4.85	6.05	7.85	9.75	12.25	14.65

Consult postmaster for exceptions and for fourth-class rates on catalogs and similar advertising matter.

Table 5-15. Summary, Annual Mailing Costs

Mail Class \ Year	Annual Costs, Dollars									
First Class <sup>(1)</sup>										
Air Mail <sup>(1)</sup>										
Priority Mail <sup>(2)</sup>										
Second Class <sup>(3)</sup>										
Parcel Post <sup>(4)</sup>										

(1) From Table 5-9.

(2) From Table 5-10.

(3) From Table 5-12.

(4) From Table 5-13.

below, however, allow rapid calculation of costs for commercially available aircraft which should provide suitable platforms for the sensors of most prospective missions. These aircraft provide a wide range of payload capability and all may be assumed for purposes of estimates to be capable of 1,609 km (1,000 mi) range and 6,090 m (20,000 ft) altitude. The unique combinations of payload, range, speed, altitude, and other characteristics of individual aircraft are generalized for the purposes of estimating costs herein.

The weight of mission equipment determines the aircraft gross weight, based on a payload-to-gross weight ratio of one to four. The gross weight required determines operating cost per mile, from Figure 5-10 and investment cost, from Figure 5-11. Aircraft speed is obtained from gross weight versus speed relationships in Figure 5-12, which is necessary in calculating the numbers of aircraft required.

Figure 5-10, operating costs per mile, is based on the cost curves in Part B, page 5-24, for fuel and oil, maintenance, storage, and insurance; pilot costs are included. The figure shows costs for the most economical type of aircraft; piston powered below 4,536 kg (10,000 lb) gross weight and jet powered above 4,536 kg (10,000 lb), based on pilot costs of \$18,000 per year for 1000 flight hours, or \$18 per flight hour. One pilot is required for the piston aircraft, two for the turbine aircraft.

Turboprop aircraft costs are not shown. This does not mean that turboprops might not be the preferred choice under some combinations of requirements. It does mean that costs in such cases would be represented with adequate accuracy by the curves shown.

## 1. CALCULATIONS

### a. Inputs Required

Cost calculations require the following inputs to be available from the definition of the observation system:

- (1) Weight of aircraft payload (mission equipment weight, including any operating personnel other than the pilot)

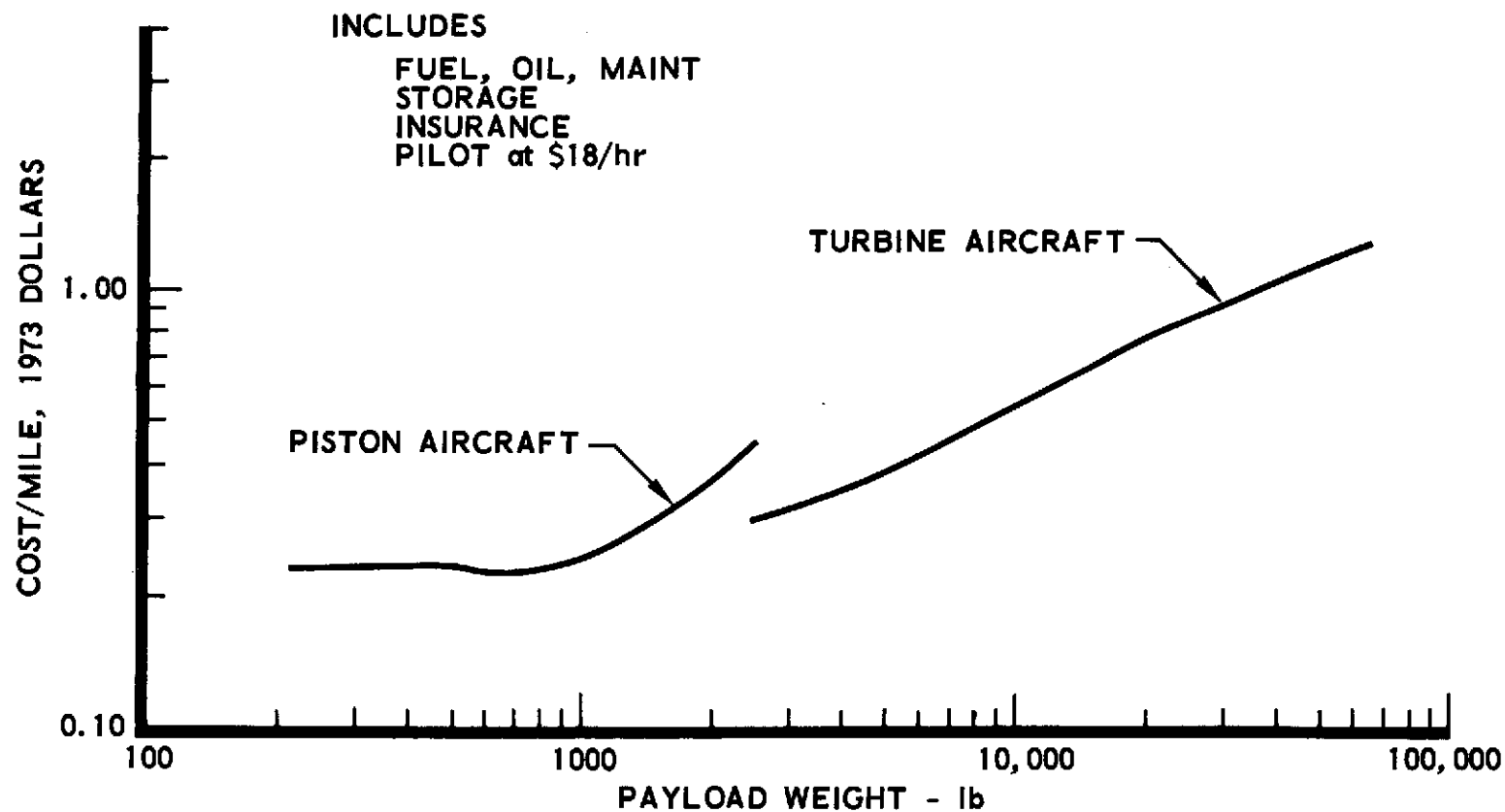


Figure 5-10. Aircraft Operating Cost Per Mile vs Payload Weight

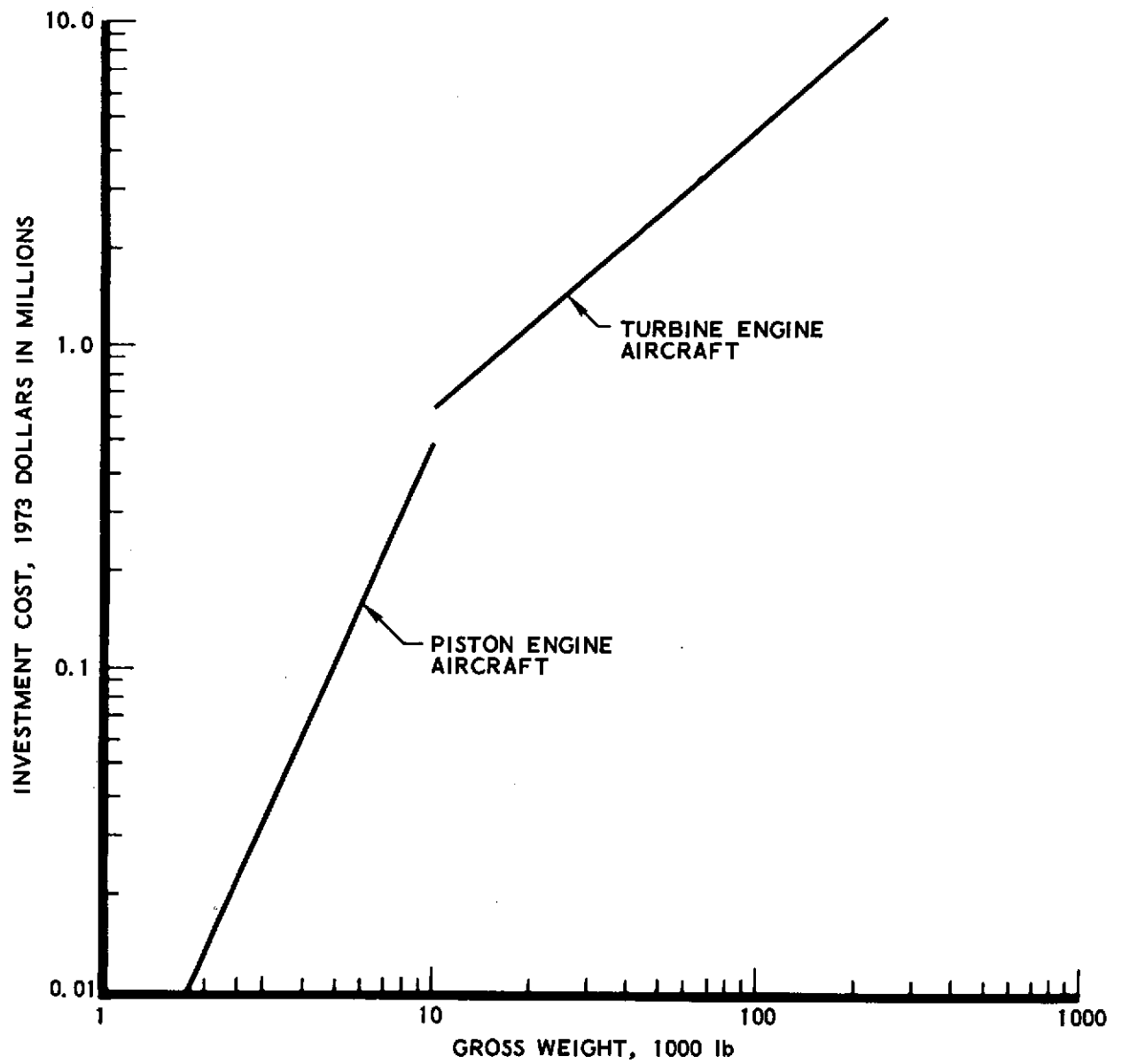


Figure 5-11. Aircraft Investment Cost vs Gross Weight

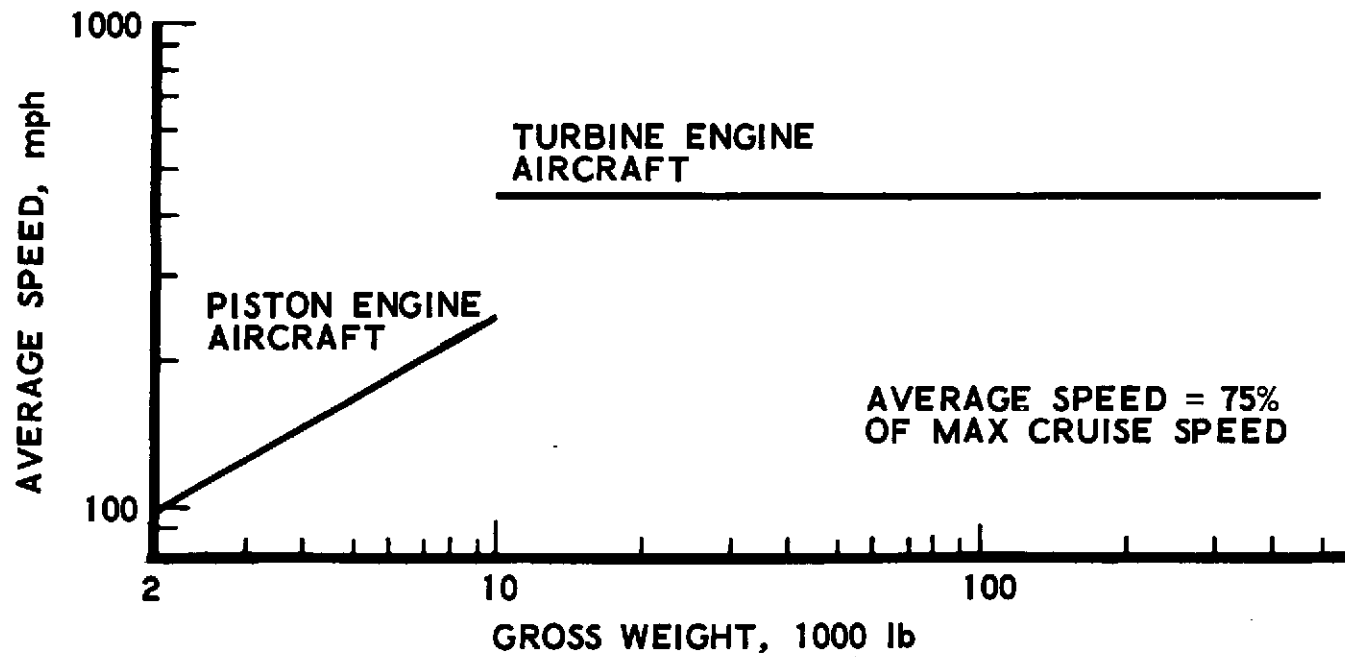


Figure 5-12. Aircraft Speed vs Gross Weight

- (2) Size of area of observation
- (3) Interval between observations
- (4) Width of observation strip (related to characteristics of the sensor(s) and to image definition requirements)
- (5) Average number of hours per day and average number of days per year suitable for observation, taking into account the effects of weather and seasons.
- (6) Schedule of implementation of system (year of first operations; build-up of area covered by year; termination schedule by year).

b. Aircraft Cost Estimates

Use the Worksheets, Tables 5-16 and 5-17, to perform calculations as follows:

- (1) Determine aircraft gross weight.  
Gross weight = (4) (payload weight)
- (2) Determine aircraft speed, miles/hour from Figure 5-12, speed versus gross weight.
- (3) Determine number of aircraft required:  
Number of aircraft =  $(365) A / WVHID$ , where
 

A	=	area covered by observation mission ( $\text{mi}^2$ )
W	=	width of observation strip (mi)
V	=	aircraft velocity (mi/hr)
H	=	hours/day, average, suitable for observation
I	=	interval between observations (number of days)
D	=	number of days/year suitable for observation.
- (4) Determine investment cost per aircraft from cost versus gross weight relationships in Figure 5-11, and total investment (cost/aircraft x number of aircraft). Where the system is implemented over more than one year, allot the total aircraft investment by year in Table 5-17 in proportion to the area covered added per year. Assume a 12-year useful life for aircraft and a residual value of 15 percent of initial investment cost.

Table 5-16. Calculation of Aircraft Costs

INPUTS REQUIRED:

Payload Weight \_\_\_\_\_ lb.

Area of Observation (A) \_\_\_\_\_ mi<sup>2</sup>.

Interval Between Observations (I) \_\_\_\_\_ days.

Width of Observation Strip (W) \_\_\_\_\_ mi.

Average Suitable Observation Time Per Day (H) \_\_\_\_\_ hrs/day.

Average Number of Days/Year Suitable for Observation (D) \_\_\_\_\_ days.

CALCULATIONS:

Aircraft Gross Weight = (4) (Payload Weight) = (4) (\_\_\_\_\_) = \_\_\_\_\_ lb.

Aircraft Speed, V, (from Figure 5-12) V = \_\_\_\_\_ mi/hr.

Number of Aircraft Required, N =  $\frac{(365)}{WVHD}$

$$N = \frac{(365) ( )}{( ) ( ) ( ) ( ) ( )} = \underline{\hspace{2cm}}$$

Investment Cost Per Aircraft (from Figure 5-11) = \$ \_\_\_\_\_/aircraft.

Total Investment Cost for Aircraft = (N) (Cost/Aircraft) = \$ \_\_\_\_\_.

Annual Cost =  $\frac{(365) (A) (Cost/Mi)}{WI}$

Obtain cost/mile from Figure 5-10.

$$\text{Annual Cost} = \frac{(365) ( ) ( )}{( ) ( )} = \$ \underline{\hspace{2cm}}.$$



Table 5-17. Aircraft Costs by Year

Input Required \ Years									
Observation Area Added (Mi <sup>2</sup> )									
Total Area Observed (Mi <sup>2</sup> )									
INVESTMENT <sup>(1)</sup> COSTS									
ANNUAL COSTS									

(1) Assume 12-year useful life and a residual value of 15 percent of investment. Enter residual value as a "negative investment" in the year after the last of use. For periods of use shorter than 12 years, residual value equals the initial investment times  $[1 - (0.85) (\text{years used}/12)]$ .

- (5) Determine annual operating cost:

$$\text{Annual cost} = \frac{(365) (A) (\text{cost/mi})}{WI}$$

where (cost/mi) is read from Figure 5-10, cost/mile versus payload weight. If the area covered is not the same for all years, then annual cost for each year in Table 5-17 is based on the area "A" being covered in that year.

## 6. COST EFFECTIVENESS

### A. INTRODUCTION

The purpose of the cost effectiveness analysis is to compare costs and required revenues of various alternative systems, designed to perform a similar mission, in order to select the most cost effective alternatives. These alternatives include both space and terrestrial-based systems. This analysis normally culminates and concludes a BRAVO analysis.

The following subsections give the instructions and information necessary to complete the cost effectiveness analysis, using the cost/revenue forms presented in the Workbook, Part 3 of Volume IV of this report.

The analysis is carried out routinely without reference to the background information (Section C) or discussion of work sheets (Section D) by following the procedure in Section B. It is recommended, however, that the analyst familiarize himself with Sections C and D the first time through as an aid to understanding the instructions in the procedures.

### B. COST EFFECTIVENESS ANALYSIS PROCEDURE

The cost effectiveness analysis is accomplished in two phases:

1. Space system comparison and selection
2. Cost effectiveness of space system(s) versus terrestrial system(s).

These phases are outlined in the following two subsections.

## 1. SPACE SYSTEM COMPARISON AND SELECTION

This phase accomplishes the selection and sequencing (to best match the projected demand and to hold costs down) of the space system approaches. Candidate space systems surviving the cost/risk analysis are included in this selection process, as well as the comparative terrestrial system. The cost comparisons between the alternative space systems are made on the basis of constant dollars. The specific steps involved in this phase of the analysis are outlined below:

Step 1 - Before starting the cost effectiveness analysis, the analyst should have the following inputs in hand:

1. The list of space system approaches selected. This list is obtained from the output of the space system optimization studies.
2. Cost streams for each space system approach selected. These cost streams are obtained as an output from the space system cost estimating program.
3. Cost streams for the ground system electronics and facilities portion of the selected space systems. These costs are obtained as an output of the terrestrial system cost estimation.
4. Cost streams, or revenue required streams in constant dollars, for the terrestrial system(s). The terrestrial system(s) competes with the space systems on an equal capability basis. The terrestrial system costs, or required revenues, are also obtained as an output of the terrestrial system cost estimation.
5. Demand stream. The product or service demand stream is obtained from the terrestrial system definition output.
6. System "start" date. The start date is the first year that costs are incurred by the space system (and supporting ground system). This date is specified by the space or supporting ground system cost stream outputs.

7. Discount rate factor,  $(1 + F)$ . The discount rate factor,  $(1 + F)$ , is computed from the rate of return on current dollars,  $r$ , and the inflation rate,  $f$ . The rate of return on current dollars is either defined by the user, or selected on the basis of industry average return rates. Typical average industry rates are as follows:

$r$  = TBD for farming industry  
 $r$  = TBD for industrial community  
 $r$  = TBD for utilities

The inflation rate is either defined by the user or based on the average U. S. inflation rate over recent years of approximately four percent\*.

Step 2 - Use the form "Cost/Revenue Analysis for Constant Dollars," page 9-3 in the Workbook (Part 3 of Volume IV of this report) for calculating the costs and revenue required in constant dollars and the net present value (NPV) of costs and revenues. The following discrete steps should be followed in completing the form for each of the selected space systems and for the competing terrestrial system (as the form applies).

1. Mark start date in first year column heading, and fill-in remaining years in sequence until the desired completion date. Note: Different equipment may be replaced at varying intervals (e. g., mission equipment, spacecraft, ground electronics, etc.). To permit different write-off periods for different equipment, the residual value and total columns should be inserted after the appropriate years corresponding to the different write-off periods.
2. Fill in the "System Cost Estimate" data input rows. These rows are identified by an asterisk. Note: The residual value and total columns should be filled in only as appropriate for the write-off period of each equipment. The total column should include a summation of the yearly costs, since the last summation, less the residual value.
3. Complete the "System Cost Estimate" summary rows: (1), (4), (9), and (13).

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\* Reference BLS Wholesale Price Index from 1967 to 1972.

4. Fill in row (14), under "System Revenues," starting with a 0 for the first year (NPV start date) and adding 1 for each succeeding year (i.e., 0, 1, 2, 3, etc. years).
5. Complete input and calculation rows: (15) - (17), (19) - (24), (26) - (31), (33) - (35), (37) - (39), (41) - (46), and (48) - (50).

Note 1) Complete the total column for row (17), and the residual value and total columns for rows (19), (22), (26), (29), (33), (37), (41), (44), and (48) only as appropriate for the equipment respective write-off periods (see Step 2 above). The totals should only include the summation of yearly NPVs, less residual NPV, after the last summation period. (Row (17) does not include any residual values.)

Note 2) Unit charge entries for rows (20), (23), (27), (30), (34), (38), (42), (45), and (49) are only made in the appropriate total column(s), as applicable to the specific equipment write-off periods.

Note 3) The individual revenue, rows (21), (24), (28), (31), (35), (39), (43), (46), and (50), are computed using the unit charge for the appropriate write-off periods.

6. Complete the "System Revenue" and "NPV of Costs" rows: (18), (25), (32), (36), (40), (47), (51), (52), and (53). Note: Rows (51) and (53) only include the total column(s).

Step 3 - Tabulate and compare the following parameters for each of the alternative space systems considered, and the competing terrestrial system (as applicable for the terrestrial system).

1. Total NPV of system costs. The total NPV of system costs is indicated in the form on page 9-3 in the Workbook, Part 3 of this report, row (53). The total is the summation of the individual years, or a summation of the several total columns, for each item.
2. Peak funding of each system. The peak total funding in any year is the peak costs as indicated in row (13) of the form on page 9-3 in the Workbook, Part 3 of this report.

3. Revenue required for each system. This is the yearly funding as indicated in row (52) in the form on page 9-3 of the Workbook. Tabulate the above three parameters in the form on page 9-15 in the Workbook, Part 3 of Volume IV of this report, for convenient comparison. The NPV is only entered in the total column, the peak revenue is only entered in the year corresponding to peak funding for each system considered and the revenue is entered yearly.

Step 4 - Select the best space system alternative based on the comparisons conducted in Step 3. The following procedure should be adhered to in optimum system selection.

1. First, review peak funding for each space system to ascertain if any budgetary constraints are violated. If any systems exceed the budgeted limit, these systems must be either deleted from the selection process or reworked through the BRAVO cycle to avoid exceeding budgetary limits.
2. Next, review the required revenue. If the required revenue of any space system appears unusually excessive, in relation to the terrestrial system revenue, this may be cause for deleting this system from the selection process or possibly reworking through the BRAVO cycle.
3. Finally, compare the NPVs of the competing space systems. Barring system deletions or concerns relating to peak funding or required revenues, the space system with the lowest NPV should be selected as the optimum system. This indicates the most economical system.

## 2. COST EFFECTIVENESS OF SPACE SYSTEM(S) VS TERRESTRIAL SYSTEM(S)

This phase involves the comparison of the selected space system(s) with the competing terrestrial system. This comparison is done on the basis of current dollars as an aid to corporate management in conducting funding predictions and cash flow analyses. The same input data required for the Space System Comparison and Selection procedures will be used for this phase of the study. The specific steps involved in this phase of the analysis are outlined below.

Step 1 - Use the form "Cost/Revenue Analysis for Current Dollars," page 9-9 in the Workbook, Part 3 of Volume IV of this report, for calculating the costs and revenue required in current dollars and the net present value (NPV) of costs and revenues. The procedure for completing this form is quite similar to the form on page 9-3 in the Workbook with a few minor exceptions to arrive at revenue in current dollars. The following discrete steps for completing the form (page 9-9 in the Workbook) are delineated as an aid for the analyst who has previously completed the form on page 9-3 in the Workbook for the same systems.

1. Complete the heading information (i. e., years, residual value, and totals) as was done for the "Constant Dollars" form on page 9-3 in the Workbook.
2. Complete the "System Cost Estimate" rows (1) through (14) by copying similar row data from the "Constant Dollars" form.
3. Complete the "System Cost Estimate" data rows (15) and (16). Note: The inflation rate,  $f$ , was previously determined as input information for computing the constant dollar discount factor,  $F$ .
4. Complete input and calculation rows (17) - (20), (22) - (27), (29) - (34), (36) - (38), (40) - (42), (44) - (49), (51) - (53).

Note 1) Some of the system revenue data from the "Constant Dollar" form (page 9-3 in the Workbook) to this "Current Dollar" form (page 9-9 in the Workbook) for the same systems and should be copied directly. Due to the different row numbering systems between the two forms, after row (14) the rows must be compared as follows:

<u>"Constant Dollars" Form</u> <u>Page 9-3 in the Workbook</u>	<u>"Current Dollars" Form</u> <u>Page 9-9 in the Workbook</u>
(15)	(17)
(16)	(19)
(22)	(25)
(26)	(29)
(29)	(32)
(33)	(36)
(37)	(40)
(41)	(44)
(44)	(47)
(48)	(51)



Note 2) Entries for rows (23), (26), (30), (33), (37), (41), (45), and (48) are only made as appropriate to the specific equipment write-off periods.

5. Complete the "System Revenue Summary" rows (21), (28), (35), (39), (43), (50), (54), and (55).

Step 2 - Tabulate and compare the current dollar cash flows, both costs and revenues, for the selected space system(s) and the terrestrial system [rows (16) and (53)]. The terrestrial costs and revenues are computed using the "Current Dollars" form (page 9-9 in the Workbook), as described for the space systems, to the extent applicable. If estimated costs for the terrestrial system are not available, then only the revenues can be compared with the space system(s). Use the form on page 9-15 in the Workbook, Part 3 of Volume IV of this report, for tabulating these cash flows.

Step 3 - The analyst must carefully review the findings in Step 2 prior to making a comparative recommendation between the space system(s) and the terrestrial system. The primary criteria should be economic. From this standpoint the system requiring the lower revenue to recover investment plus return on investment is the most economical system. Other factors, however, such as cash flow requirements (current dollar costs) may be deciding criteria in the event budgetary allowances are exceeded or estimated revenues are very close. Therefore, all pertinent economic factors determined by this cost effectiveness analysis should be played against the specific study objectives and ground rules to insure that any recommendation made does not violate case constraints.

## C. BACKGROUND INFORMATION

### 1. NOMENCLATURE

The nomenclature used in defining the various economic terms and equations is presented below for easy reference.

Cost in constant dollars in year n . . . . .	$A_n$
Revenue in constant dollars in year n . . . . .	$R_n$
Revenue in current dollars in year n . . . . .	$R_{nr}$
Rate of return on constant dollars . . . . . (equal purchasing power)	$F$
Rate of return on current dollars . . . . . (equal face value dollars)	$r$
Inflation rate . . . . .	$f$
Unit demand in year n . . . . .	$D_n$
Unit charge rate for constant dollars . . . . .	$C$
Unit charge rate for current dollars . . . . .	$C_r$
Years from start . . . . .	$n$

## 2. ECONOMIC RELATIONSHIPS

In order to compare alternative system costs and required revenues on a valid economic basis, certain economic relationships are defined. These economic relationships, bearing on the cost and required revenue calculations to be performed in comparing alternative systems, are presented below.

### a. Cost Streams

Cost streams (the year-by-year costs required to develop, build, and operate a system) can be defined in either constant or current dollars. Use of constant dollars, or equal purchasing power dollars, provides a measurement of the system costs on a fixed-dollar basis (e. g., a 1973 dollar), and is generally the approach taken in estimating costs of future systems. Use of current dollars, or equal face value dollars, provides a better measure of the true cash flow in an inflationary period where a dollar has less purchasing power as the years progress. The mathematical representation of a cost stream in either constant or current dollars is shown below.

In constant dollars:  $A_0 + A_1 + A_2 \dots A_n$

In current dollars:  $A_0(1 + f)^0 + A_1(1 + f)^1 + A_2(1 + f)^2 \dots A_n(1 + f)^n$

b. Revenue Streams

Revenue streams (the year-by-year dollar return from an investment) can also be expressed in constant or current dollars as follows:

In constant dollars:  $R_0 + R_1 + R_2 \dots R_n$

In current dollars:  $R_0(1+f)^0 + R_1(1+f)^1 + R_2(1+f)^2 \dots R_n(1+f)^n$   
or

In current dollars:  $R_{0r} + R_{1r} + R_{2r} \dots R_{nr}$   
(where  $R_{nr}$  includes the effects of inflation)

c. Rate of Return Relationship

The relationship between the rate of return on constant dollars and current dollars, showing the effect of inflation, is presented below.

$$(1 + F) = \left( \frac{1 + r}{1 + f} \right)$$

This equation points out the fact that the rate of return on current dollars, (r), which is similar to bank interest rate, must be higher than the inflation rate, (f), if the equal purchasing power rate of return, (F), is to be a positive number.

d. Net Present Value (NPV)

The NPV relates future cost or revenue streams to their present economic value, based on a specified rate of return. The NPV of a stream of constant or current dollars is exactly the same, provided the rate of returns are consistent and the present year of reference is the same (obviously a 1973 current dollar is the same as a 1973 constant dollar). The NPV derivation for the cost and revenue streams is presented below.

$$\text{Cost Stream: NPV} = \sum_0^n A_n (1 + F)^{-n}$$

$$\text{Revenue Stream: NPV} = \sum_0^n R_n (1 + F)^{-n}$$

or

$$\text{Revenue Stream: NPV} = \sum_0^n R_{nr} (1 + r)^{-n}$$

e. Unit Charge Rates

The charge rate per unit of product delivered (e.g., communication circuits, kilowatts of power, etc.) is a constant over a specified period of time. The revenue returned per year is the charge rate times the demand for units per year. This relationship is presented in the following equations for constant and current dollar revenues:

$$\text{In constant dollars: } R_n = C D_n, \text{ or } C = \frac{R_n}{D_n}$$

$$\text{In current dollars: } R_{nr} = C_r D_n, \text{ or } C_r = \frac{R_{nr}}{D_n}$$

f. Revenue Calculation

The total revenue required from an operating system should return all of the capital invested in the system (R&D, investment, and operations) plus an appropriate rate of return (interest) on all of the capital invested. A simple, yet economically viable, method of calculating the revenue required is to set the NPV of the total revenue equal to the NPV of the total costs. The revenue required can be defined in terms of constant dollars or current dollars by using the appropriate relationships. Using the economic relationships previously defined, the equations for the required revenues are presented in both constant and current dollars as follows.

(1) Revenue in Constant Dollars

$$\sum_0^n R_n (1 + F)^{-n} = \sum_0^n A_n (1 + F)^{-n}$$

or 
$$\sum_0^n CD_n (1 + F)^{-n} = \sum_0^n A_n (1 + F)^{-n}$$

then 
$$C = \frac{\sum_0^n A_n (1 + F)^{-n}}{\sum_0^n D_n (1 + F)^{-n}}$$

and 
$$R_n = R_n = CD_n$$

(2) Revenue in Current Dollars

$$\sum_0^n R_{nr} (1 + r)^{-n} = \sum_0^n A_n (1 + F)^{-n}$$

or 
$$\sum_0^n C_r D_n (1 + r)^{-n} = \sum_0^n A_n (1 + F)^{-n}$$

then 
$$C_r = \frac{\sum_0^n A_n (1 + F)^{-n}}{\sum_0^n D_n (1 + r)^{-n}}$$

and 
$$R_{nr} = C_r D_n$$

3. COST/REVENUE ANALYSIS WORK SHEETS

Computation of cost and revenue streams is accomplished on analysis worksheets. Sample worksheets are provided in the Workbook, Part 3 of Volume IV of this Study 2.4 final report. The following two subsections describe these worksheets for cost and revenue streams in constant dollars and in current dollars.

a. Cost/Revenue Streams in Constant Dollars

The form "Cost/Revenue Analysis for Constant Dollars," page 9-3 in the Workbook, Part 3 of Volume IV of this report, presents a sample worksheet for computing both satellite system costs and required revenue streams in constant dollars.

All calculations are accomplished on a year-by-year basis, with the total being a summation of the yearly results. The residual value specifically refers to the system cost estimates. It defines the residual constant dollar value remaining in each satellite or ground system investment (if any) at the conclusion of the write-off period for that particular investment. The residual value appears as a negative cost in the year the specific equipment is to be written off, and would be subtracted from the corresponding investment costs occurring in that year (possibly resulting in a negative investment).

The system cost estimates are broken down into satellite, launch vehicle, and ground system costs. The satellite costs are further divided into R&D, investment, and operations. In order to provide for the possibility of writing off the satellite mission equipment or spacecraft over different time periods (the mission equipment may be revised several times over the life of the spacecraft), their costs are accounted for separately for the satellite R&D and investments. The same is true for ground system investment where the electronics and support facilities are separately listed to permit different write-off periods. The total system cost, for space systems, is the summation of the separate satellite, launch vehicle, and ground system costs. For terrestrial systems, the total system cost would be only that included under the ground system costs.

The computation of the required system revenues (to return invested capital plus interest) is carried out separately for each cost element. In this manner, differing write-off periods can be considered for each element (e.g., spacecraft, mission equipment, etc.). Calculation of revenues requires determining the NPV of each of the cost elements and the unit demand. Using the sample worksheets in the Workbook, Part 3 of Volume IV of this report, the unit charge rate is obtained separately for each of the cost elements and the element required revenue is simply the multiple of its unit charge rate and the unit demand. The total system unit charge rate and revenue is the summation of the individual element charge rates and revenues.

b. Cost/Revenue Streams in Current Dollars

The form "Cost/Revenue Analyses for Current Dollars," page 9-9 in the Workbook, presents a sample worksheet for computing both satellite system cost and required revenue streams in current dollars.

The calculations are accomplished in exactly the same manner as for the "Constant Dollar" form on page 9-2 in the Workbook, with the following exceptions:

1. Though the system costs are individually computed in terms of constant dollars, as per the "Constant Dollars" form, the total system costs are computed both in constant and current dollars.
2. The required revenue is computed in current dollars. This is accomplished, as described in Section B, by calculating the element charge rates in current dollars rather than constant dollars. The computed revenue is then also in current dollars.